SEAMARC I MIDRANGE SIDESCAN SONAR SURVEY OF FLEMISH PASS, EAST OF THE GRAND BANKS OF NEWFOUNDLAND

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ABSTRACT

A 775 km^2 area of the west-central Flemish Pass, east of the Grand Banks of Newfoundland , was surveyed using the midrange sidescan sonar system Sea MARC I. The mid-slope seabed within the survey area is generally smooth with very little relief; the upper slope is dominated by extensive iceberg scouring and the lower slope and floor of the pass have slump scars and mass-flow deposits, partly masked by younger sediment deposition.

The upper continental slope between 300 and 700 m has been scoured extensively by grounded icebergs and two distinct scour populations, which appear to be depth related, are observed. Interpretations of the sidescan and sub-bottom profiles indicate that scours are generally between 200 and 1000 m in length, 25 to 100 m wide, and have an average relief of about 2 m. The geophysical evidence suggests that sediment failure (i.e. mass wasting, slumping) has probably not occurred as a result of seabed scouring by icebergs.

In the northern section of the survey, a 200 km^2 area of slumped or mass-flow deposit is observed. The slumped terrain is generally hummocky and apparently lineated parallel to the slope contours. Towards the southern end of this disturbed area, the distinctive lineations become fragmentary, and have a mottled appearance on the sidescan sonographs. Immediately east of the slump at the bottom of the continental slope (1050 m) and farther up the slope (850 m) two pronounced scarps occur which run NE/SW with relief of approximately 30 and 50 m, respectively. Huntec High resolution seismic profiles show that both scarps and the

mass flow deposits are mantled by acoustically well stratified sediments. A tentative stratigraphy based on a core that penetrates this stratified unit suggests that the mass flow deposits are at least mid-Wisconsinan in age.

In the southern survey area, a low hill rises about 190 m above the floor of Flemish Pass. Minor mass wasting channels and a moat are associated with this structure, which is cut by a prominent scarp running ENE to WSW. Mound-like features, possibly elongate, appear to cut stratified sediments on the floor of the pass and sidescan sonographs show radiating lineations running down the sides of these features.

This open file report presents a photographic mosaic of the sidescan images, selected sidescan sonographs and sub-bottom profiles, and a geologic interpretation.

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INTRODUCTION

This study is a joint research program between the Centre for Cold Ocean Resources Engineering (C-CORE) and the Atlantic Geoscience Centre, Geological Survey of Canada, Bedford Institute of Oceanography (BIO). The project is within C-CORE's mandate to undertake research that will assist in the safe and orderly development of Canada's resources in cold and ice frequented oceans. The project is part of the Seabed Stability on the Continental Slope project within the Long Term Studies of Marine Geology Program of the Canada Energy Research, and Development Program.

Sediment failure has been reported as very common on the tectonically passive, Atlantic margin (Moore, 1977; Embley, 1980) although sediment failure on a large scale similar to that following the 1929 Grand Banks earthquake have recurrence intervals of perhaps hundreds of thousands of years (Piper and Normark, 1982). The objectives of the Federal government program are to identify geological constraints to exploration and production of hydrocarbons from the offshore deep-sea continental margin. Attention in this study will be directed primarily to mass movement features and sediment stability problems of the seabed.

The purpose of the Sea MARC I sidescan survey was to investigate seabed morphology and to map the distribution of features such as sediment slumps, slides and slide scars, debris flows, and deep-sea iceberg scours. The survey was undertaken in the west central Flemish Pass (Figure 1), east of the Grand Banks of Newfoundland, between 46°50'W and 47°20'W, where exploratory drilling for hydrocarbons is expected to recommence during 1985. Using the preliminary data obtained from this survey, experiments and further ground truthing studies will be undertaken to determine geotechnical characteristics of continental slope sediments, ages of iceberg scouring populations and the development of a sediment dynamics model for the area surveyed. In addition, the rationale for sediment/seabed failure initiation processes occurring in particular depth environments will be evaluated and the results used to predict frequency of occurrence and the potential instability of the sea floor in the surveyed area.

METHODS

The survey was undertaken on CSS **HUDSON** cruise HU84-035 using the Sea MARC I deep-tow system, with 27 and 30 kHz sidescan sonar transducers and a 4.5 kHz sub-bottom profiler (Kosalos and Chayes, 1983). The Sea MARC vehicle is neutrally buoyant and is towed astern of the ship, about 300 m off the seabed. A 5 km sidescan swath width was used throughout the survey. Data from the sidescan sonar system is digitally recorded, and processed in real time to give orthorectified images with slant range corrections. At a later date, these orthorectified sidescan images were compiled manually into a mosaic at a scale of 1:40 000. The sidescan images were cut and either spaced or overlapped where recorder paper advance speed was not correctly adjusted to offset tow speed variations.

Ship's navigation was by the BIONAV system which integrates LORAN C and satellite navigation data; it is accurate to within 200 m. Unfortunately, positioning of the Sea MARC tow vehicle was unsuccessful during the survey. Both the wire-out indicator and the Oceano short-baseline navigation system failed to operate successfully for any significant length of time. Bathymetry during the survey was determined using the ship's 12 kHz profiler. Depths on Sea MARC 4.5 kHz sub-bottom profiles are determined by summing a pressure-derived vehicle depth and an acoustically determined vehicle altitude; in this Sea MARC data set, the pressure depths are unreliable and depths referenced in this report refer to those determined using the ship's 12 kHz profiler. A Huntec deep-tow seismic (DTS) profile through the study area was collected earlier on cruise HU80-010 (Fader, 1980); these data are also presented here.

Figure 2 is a map showing locations of the various seismic lines illustrated in the text and Figure 3 shows the distribution of the principal geomorphological features within the survey area.

OCEANOGRAPHY

North of Flemish Pass off the Labrador Shelf, the Labrador current flows near the surface with velocities exceeding 50 cm s^{-1} in the 'core' region (extending down to 250-300 m). Below the 300 m pycnocline is the North Atlantic Intermediate Water (NAIW) which appears to be largely barotropic. Current meters installed by petroleum industry operators (Seaconsult, 1978) in the Flemish Pass (Figure 3), show a strong and persistent south flowing residual current. The magnitude of this residual flow ranges between 15 to 30 cm s^{-1}, with the highest value for the deepest meter (ca. 40 m above the seabed) reaching 19 cm s^{-1}. The deeper part of the NAIW is part of the Western Boundary Undercurrent.

BATHYMETRY

The bathymetric map in Figure 1 is based on the detailed surveys of Monahan and MacNab (1974), which have been modified using Sea MARC I sidescan data. The western flank of Flemish Pass has an overall concave profile, from a shelf break at 240 to 280 m, down to the floor of the Pass at just below 1100 m. No major valleys cut the slope, although local irregularities are visible both in bathymetric profiles and sidescan sonographs. The floor of the Pass has irregular relief on the scale of a few to a few tens of metres. Near the southwestern end of the survey area there is a low hill that rises 190 m above the floor of the Pass (Figure 20).

GEOLOGICAL SETTING

Flemish Pass is a U-shaped deep-sea trough which separates the Grand Banks of Newfoundland from Flemish Cap; the latter being identified as a segment of the continental crust which became separated from the North American continent (Grant, 1972). The Pass has an overall length of about 265 km with a maximum width of about 45 km at the 1000 m isobath. Seismic profiles across southern Flemish Pass show a broad, relatively shallow-relief moat on the western side, whereas the eastern side is accentuated by mounded deposition (Kennard, 1982) (see also Grant, op. cit., p.1407, 1414). These erosional and depositional features are formed under the influence of the strong, southward flowing Western Boundary Undercurrent; the deposits have tentatively been classified as contourites (Kennard, op. cit.).

The shelf break at the eastern edge of the Grand Banks, west of the study area is abrupt, and deepens from 240 m in the south to 280 m in the north. It was thus probably not emergent during maximum glacial lowstands of sea level. It is not clear whether, or how frequently, glacial ice reached the outer edge of the Grand Banks during the Pleistocene. Recent studies utilizing seismic, sidescan and sample control suggest that Wisconsinan ice, extended across the entire Grand Banks (Fader, BIO, pers. comm., 1985). Storm reworking of shelf edge sands may have contributed sediment to the continental slope, in the manner suggested by Stanley et al. (1971) or Hill and Bowen (1983).

Monahan and MacNab (1974) recognized two distinct geomorphological zones within the area surveyed by Sea MARC I. They described the continental slope from the Grand Bank Shelf to the 650 m isobath as being characterized by shallow trough like depressions and also noted that the contact with the Grand Bank Shelf and the continental slope is generally gradational or marked by a break in the slope. The middle and lower slope of the Pass below 650 m is typically smooth and featureless, except for long, low undulations and occasional breaks in the slope

(Monahan and MacNab, op. cit., Figure 4). The transition between the middle and lower zones is almost always abrupt, marked by a small trough.

The slope of the western flank of Flemish Pass is concave decreasing from 2.3° on the upper slope to 0.06° near the floor of the Pass. This area is underlain by a prograding sequence of late Cenozoic sediments which are in part a continuation of prograding strata on the eastern Grand Banks (Grant, 1973). Wellsite surveys (Geonautics, 1981a,b) indicate a sub-surface unit of unconsolidated sediments on the floor of the Pass of variable thickness of up to 60 m; the thickest accumulation is toward the northeastern entrance of the Pass and the thinnest toward the southern entrance. The sediments progressively thin upwards, along the flanks of the pass. This unit has been interpreted as Holocene in age (Geonautics, 1981b). Draping this unit (in the study area) is a thin surficial unit rarely greater than 7 m thick on the floor of the pass (Geomarine, 1979). Small scale slump features have been identified on the western flank of Flemish Pass (Geomarine, op. cit.).

Alam (1979) who examined and described three cores from the western flank of Flemish Pass (Esso cores 3-1; 4-1; 4-2), distinguished three sedimentary facies. Olive-grey, silty mud characterised late Holocene sedimentation, probably dominated by the Western Boundary Undercurrent. The early Holocene, and possibly other warm interstadials, were characterized by carbonate-rich sandy mud, with substantial ice-rafted debris, and higher abundances of sub-arctic foraminifera and coccoliths.

Glacial maxima were characterized by the accumulation of muds with some thin sandy turbidities, presumably derived from the Grand Banks at times of lowered sea level. Core 3-1 (Figure 3) is located on the floor of Flemish Pass within the study area and has a sedimentation rate about half of that in cores 4-1 and 4-2 which are situated in 850 m of water about 25 km north of the study area. Alam (op. cit.) suggested that turbidities at sub-bottom depths varying between 2 and 6 m represent the late Wisconsinan maximum lowering of sea level. This chronology has not been substantiated directly by either radiocarbon dates nor oxygen isotope stratigraphy, but is consistent with the recent stratigraphic work of Schafer et al. (1985).

DESCRIPTION OF SEABED FEATURES

Introduction

Sub-bottom penetration using the 4.5 kHz Sea MARC I and 3.5 kHz profilers was generally poor; the best resolution-penetration sub-bottom information available in the survey area is a Huntec DTS profile from cruise HU80-010 (Fader, 1980). Geomorphological features have been identified using Sea MARC I sidescan and the Huntec DTS profile.

Huntec DTS profiles reveal an upper continental slope with well stratified sediments that are cut by iceberg scours (Figure 4). Some scours appear to have been filled by stratified sediment near the lower limit of scouring. There is a small shallow trough (Figure 5) near the lower limit of iceberg scouring at about 725 m. The mid- and lower continental slope is generally featureless with well stratified sediments apparently covering the entire area. Sediment accumulation is variable across the slope, but appears to be especially thick on small terraces above escarpments found on the lower slope (Figure 15). There is, however, only a slight increase in sediment thickness passing from the mid-slope to the floor of Flemish Pass.

Along the floor of the Flemish Pass Huntec DTS profiles show a number of distinctive depositional features. At the northern end of the survey, well stratified sediments cover acoustically transparent sediments (Figure 6) that are interpreted as mass-flow deposits (see below). Towards the centre of the survey, thick, well stratified sediment is cut by sediment mounds (Figure 13). At the southern end of the survey, the wavy character of the seabed and internal acoustical reflectors (Figure 22) suggests the development of sediment waves by the Western Boundary Undercurrent.

Iceberg Scours

The sidescan sonographs and 12 kHz bathymetric profiles show extensive iceberg scouring on the shelf edge and upper western slope of the Flemish Pass between 350 and 700 m water depth (Figures 3, 7 and 8); in addition, the sidescan sonographs show features with blurred definitions between 300 and 350 m which may be iceberg scours. These data indicate that whereas iceberg scours end abruptly on the lower slope there is a very gradual disappearance of scours towards the shallower water above 350 m.

Two distinct populations of iceberg scours are identified on the sidescan sonographs based upon overall scour dimensions shapes and density of occurrence (Figure 8). The dividing line between the two populations is well defined between 500 and 510 m.

Scours in the upper population trend generally in a N/S direction, are linear to curvilinar and follow the slope contours; few of the scours trend in an E/W direction. Scour density is greater in this upper zone. Scours have an apparent length between 75 and 700 m (with smaller scours occuring in the shallower waters), a width between 25 and 40 m and a maximum relief of about 2 metres.

Iceberg scours in the second population are generally larger in overall dimensions and are found associated with numerous pits and craters. Scours of the second population are linear to curvilinear, follow the slope contours and also have a predominantly N/S trend with a few trending upslope/downslope in a E/W direction. Scour density in this lower zone is not as great as that in the upper scour population. Scours generally range in length between 100 and 1000 m, have a width between 50 and 90 m and a maximum relief of about 3 m. Pits in this zone have diameters smaller than 20 metres with craters averaging between 75 and 100 m in width (Figure 8). Fader and King (1981) noted similar features and relationships in the adjacent shallower Grand Banks area.

Huntec DTS data indicate that sediment is conformably draped over at least part of the iceberg scoured surface (Figure 4), suggesting that these scours are relict and probably predate the Holocene. Cores are needed from the scoured area to substantiate this hypothesis.

There is no evidence of sediment failure due to iceberg scouring in either of the two zones.

MASS FLOW DEPOSITS

In the northern part of the survey area on the floor of Flemish Pass, Huntec DTS profiles (Figure 6), show a near-surface acoustically homogeneous unit, 10 - 15 msec (8-12 m) thick with a hummocky upper surface. It is conformably overlain by thin stratified sediment (Figures 6 and 9). This hummocky relief was recognized earlier by Geomarine (1979) in a wellsite survey and interpreted as a slump. The deposit covers an area of just under 200 km^2 at the bottom of the continental slope (Figure 3). Sea MARC sidescan sonographs show a muted pattern of curvilinear ridges up to 5 km long at the northern end, but is discontinuous to the south (Figure 10).

This hummocky deposit has a rough surficial profile and a transparent acoustical character which is typical of both debris flows (Embley, 1976) and rotational slumps (Piper et al., 1985). The surface ridges may be similar to those described from debris flows by Prior et al. (1984), muted by subsequent sediment accumulation or they may also be the result of subsequent erosion by the strong currents that exist in the area (Seaconsult, 1978; Kennard, 1982).

Piston core #3-1, 6 m in length, collected from the area of the mass-flow deposit (Figure 3), has been examined by Alam (1979) who interprets the Holocene-Pleistocene boundary as occurring at a depth of about 1 m, with two deeper turbidite rich horizons possible representing isotopic stages 2 and 4. There is no sedimentologic evidence that the core penetrated through the upper acoustically stratified horizon overlying the mass-flow deposit; this horizon varies in thickness between 3 and 10 m. Although the chronology is tentative, it suggests that the mass-flow deposit is at least as old as mid-Wisconsinan.

The initiation mechanism for this particular slope failure (slump or debris flow) is uncertain. It may correlate with the maximum ice advance across the Grand Banks of Newfoundland postulated by King and Fader (1985) and associated ice related instabilities. Huntec DTS data collected 2.7 km upslope from the deposit, indicates a small sub-bottom irregularity about 3 km long that may be a slide scar (Figure 11). Several scarps are also visible on the Sea MARC sidescan sonographs (Figures 15 and 16) and are discussed below.

SEABED MOUNDS

Toward the southern end of the survey, near the proposed Esso wellsite FP-1 (Figure 1), the port sidescan sonograph records two lineated mound-like features (Figure 12). These mound-like features extend over to the starboard sidescan sonograph where they appear with must less clarity. Huntec DTS profiles (Figure 13) about 4.5 km east of the Sea MARC survey line (Figures 1 and 2) show mounds that rise about 5 m above the seabed. These mounds are internally acoustically homogeneous and consist of incoherent reflectors. Acoustically stratified sediments some 10 ms (8 m) thick occur between the mounds and the reflections terminate at the mound flanks with a slight up-bending. Buried mounds with similar acoustic characteristics are also visible (Figure 13). Both the mounds and the stratified sediment appear to overlie a horizon of acoustically homogeneous sediment 5 to 15 ms (4 to 12 m) thick that rests on a relatively flat deeper stratified sediment horizon. The upper surface of the unstratified unit is irregular, and the surface stratified sediments appear draped over these irregularities.

The unstratified sediment with a rough upper surface thus resembles the mass-flow deposits at the northern end of the survey area. The mounds resemble diapirs, such as those described by Piper and Sparkes (1985) from the Scotian Slope. An alternative explanation would imply that the unstratified material is till, and the mounds are lift-off moraines as described by King and Fader (1985). There is, however, no independant evidence for a grounded ice sheet at a water depth of 1100 m in Flemish Pass; evidence of grounded ice has not been seen below 600 m on the Scotian or Labrador Slopes. Furthermore, the presence of several tens of metres of stratified sediment on the flanks of Flemish Pass, apparently correlative with the section on the floor of the Pass, is inconsistent with a model of grounded ice resting on the floor of the Pass.

It is not clear from the sidescan sonographs whether the mounds are truly ridges, or whether the ridges are segmented.

SCARPS

Two types of scarps are seen in the study area. Arcuate irregular scarps that appear to be the headwall scarps of regressive slides are seen in the southern section of the survey (Figures 12 and 14), and on the flanks of the low hill that rises above the floor of the Pass. Larger, less irregular, linear scarps of uncertain origin occur near the bottom of the west flank of Flemish Pass.

The smaller of the two arcuate slide scarps is located on the floor of Flemish Pass. It is C-shaped, about 0.5 km wide, 1 km long and about 10 m high (Figure 12). The 4.5 kHz sub-bottom profiler data shows that acoustical stratification is better developed within the scar. The second scar is further upslope and is more extensive (3 km long, 1 km wide) but with similar relief (Figure 14).

In addition, three other large linear scarps have been recognized (Figure 3), of which two are located at the bottom of the eastern Grand Banks slope, and the third on the slope at a depth of 850 m.

The single sidescan profile indicates that the scarp on the continental slope is about 2.5 km long (possibly longer), and has a vertical displacement of about 50 m. The structure can be clearly identified from the Huntec DTS profile (Figure 15), and on the port sidescan sonograph, as a prominent but diffuse reflector which fades out towards the margin of the record. The Huntec DTS profile shows a drape of surficial sediment resting unconformably on strata truncated by the scarp. There may have been a shallow depression immediately at the base of the scarp, since sediment thickness appears greater here.

There is a much larger scarp at the base of the continental slope (Figures 16 and 17). This feature, has about 30 m relief and is approximately 6 km long. It is located about 5 km upslope of the mass flow deposits. The feature has an overall C-shape, bordering a broad depression (Figure 18). Sediment within this depression appears to be well stratified.

The third scarp (Figure 14) is located immediately southeast of the submarine hill. Interpretation of the sidescan sonographs suggest that this scarp may have the largest vertical displacement of the scarps examined, but unfortunately the seismic reflection system did not track immediately over it. Unlike the other scarps, this scarp trends ENE to WSW (Figures 3 and 14). Immediately at the base of the scarp is a moat (Figures 3 and 14), about 1.5 km in length.

GULLIES AND CHANNELS

A feature interpreted as a gully partly infilled by later sediment is illustrated in Figure 19. The starboard sidescan sonograph shows the feature to be bounded on one side by a well-defined escarpment (which is a gentle incline immediately under the Sea MARC vehicle, as indicated by the 4.5 kHz profiler) and on the other side by a much smoother ridge. The floor of the gully appears to have accumulated fine sediment which may have masked original physiography. Toward the southern end of the feature, occur a set of linear raised features, each of which has a maximum length of about 100 m. These features may be either dislodged blocks from the adjacent scarp, or more likely, localized ridges, which are offset from the main smaller ridge that parallels the scarp. These features are immediately upslope of the mound-like features, but no genetic relationship is evident between them.

A number of linear to arcuate low relief features, interpreted as channels (Figures 14 and 19) are seen in the southern survey area.

Along the lower slope, the 4.5 kHz profiles show a very undulatory seabed (Figure 21), some of which may reflect small, minor channels for downslope mass sediment transport.

SEDIMENT WAVES

On the floor of Flemish Pass, at the southern end of the survey area, the Huntec DTS profile shows sediment waves developed in surficial stratified sediments (Figure 22). These waves are assymetrical in cross section and show slight up-section migration of the crest to the southwest. Their dimensions are similar to those described from beneath the Western Boundary Undercurrent further north in the Labrador Sea (Chough et al., 1985).

CONCLUSIONS

Huntec DTS profiles in the northern part of the survey area across the western flank of Flemish Pass show a surface layer of stratified sediments overlying old scarps on the continental slope, and mass-flow deposits which may be either slumps or debris flows on the floor of the Pass. Preliminary core data suggests that both scarps and mass flow deposits are at least mid-Wisconsinan in age, and probably older and may possibly relate to Wisconsinan glacial ice that advanced across the Grand Banks of Newfoundland. Fresher-looking scarps in the southern part of the survey area have not been completely mantled by sediment and may be younger. Sediment waves in the southern part of the survey area, on the floor of the Pass, are the result of powerful bottom currents. Some sculpting of the mass flow deposit in the northern part of the survey area may also result from bottom current activity, or may be surface ridges on a debris flow muted by later sediment deposition. Locally derived mounds which may result from the mass flow deposit appear to rise 5 m above the regional sea floor. These mounds superficially resemble glacial lift-off moraines that are widespread on the continental shelf, but the pressure of grounded ice as their origin in a water depth of 1100 m is intuitively unreasonable, and the thickening of stratified sediment from the floor of the pass up the lower continental slope is inconsistent with an ice-margin model of sedimentation.

IMPLICATIONS FOR HYDROCARBON DEVELOPMENT

The continental slope west of Flemish Pass is similar to many other areas of continental slope off eastern Canada. It shows relict iceberg scouring to depths of about 650 m. There are some scarps and mass flow deposits that appear to be mid-Wisconsinan or older, that could have been triggered by a large earthquake. Recent seismic source models of Basham and Adams (1982) suggest that large earthquakes occur occasionally throughout the entire length of the East Coast continental margin. No evidence has been seen for recent sediment failure. Although strong near bottom currents have been measured within Flemish Pass, there are few surficial sedimentary features other than the sediment waves in the south of the study area that can be ascribed to their activity. The features interpreted as mounds may be evidence of near-surface sediment instability, and need further investigation. They are unlikely to be a significant seabed hazard since they do not appear to have a deep seated origin.

REFERENCES CITED

Alam, M., 1979. The effect of Pleistocene climatic changes on the sediments around the Grand Banks. Ph.D. Thesis, Dalhousie University, N.S., Canada, 295pp.

Basham, P.W. and Adams, J., 1982. Earthquake hazards to offshore development on the eastern Canadian continental shelves. Proc. 2nd. Can. Conf. on Marine Geotech. Engineering, 6p.

Chough, S.R., Mosher, D.C., Srivastava, S.P., 1985. Ocean Drilling Program (ODP) Site Survey (Hudson 84-030) in the Labrador Sea: 3.5 kHz profiles, (Manuscript).

Embley, R.W., 1976. New evidence for the occurrence of the debris flow deposits in deep Sea. Geology, V. 4, pp.371-374.

Embley, R.W., 1980. The role of mass transport in the distribution and character of deep-ocean sediments in the Atlantic. Mar. Geology, V. 38, pp.23-50.

Fader, G.B., 1980. Cruise Report HU80-010, Unpublished BIO Rept., 5p.

Fader, G.B., King, L.H., 1981. A reconnaissance study of the surficial geology of the Grand Banks of Newfoundland. Current Res., Part A., GSC Paper 81-1A, pp.45-56.

Geomarine Ltd., 1979. Wellsite Survey, Esso-Voyager Gabriel C-60, Flemish Pass. Report for Esso Resources Canada, Ltd., 45pp.

Geonautics Ltd., 1981a. Draft Report on Flemish Pass. Drillsite investigations for Esso Resources Canada Ltd., 39pp.

Geonautics Ltd., 1981b. Final Report on Flemish Pass (FP-1). Drillsite investigations for Esso Resources Canada Ltd., 30pp.

Grant, A.C., 1972. The continental margin off Labrador and eastern Newfoundland - morphology and geology. Can. J. Earth Sciences, V. 9, pp. 1394-1430.

Grant, A.C., 1973. Geological and geophysical results bearing upon the structural history of the Flemish Cap region. G.S.C. Paper 71-23, pp. 373-389.

Hill, P.R. and Bowen, A.J., 1983. Modern sediment dynamics at the shelf-slope boundary off Nova Scotia. In: The Shelfbreak: Critical interface on continental margins (Eds. D.J. Stanley and G.T. Moore)., Spec. Publ. SEPM, No. 33, pp.265-276.

Kennard, L.R., 1982. Mounds, Moats and Ridges: Seismic evidence for deep current-influenced deposition east of Newfoundland. JOA, Halifax, Canada. 2-13, August 1982, Abstracts, pp. 24-25.

King, L., and Fader, G.B., 1985. Wisconsinan glaciation on the continental shelf - southeast Atlantic Canada. Open File Report No. 1126, 87p.

Kosalos, J.G., and Chayes, D.N., 1983. A portable system for ocean bottom imaging and charting. OCEANS 83 (Proceedings of the Third Working Symposium on Oceanographic Data Systems), pp. 1-8.

Monahan, D., and MacNab, R.F., 1974. Macro- and meso- morphology of Flemish Cap, Flemish Pass, and the northeastern Grand Banks of Newfoundland. In: Offshore Geology of Eastern Canada, Geological Survey of Canada, Paper 74-30, pp. 207-216 + CHS Maps 830A and 830M.

Moore, D.G., 1977. The geology of large submarine slides, in: Voight (Ed.), Mechanics of Landslides and Avalanches, Geol. Soc. Amer., Special Publication.

Piper, D.J.W., 1979. Informal Report on Flemish Pass and Davis Strait cores. Submitted to Imperial Oil Ltd., 6pp.

Piper, D.J.W., Farre, J.A., and Shor, A., 1985. Late Quaternary Slumps and Debris flows on the Scotian Slope, Bull. Geol. Soc. America (in press.).

Piper, D.J.W. and Normark, W.R., 1982. Effects of the 1929 Grand Banks earthquake on the continental slope off Eastern Canada; in Current Research, Part B, Geological Survey of Canada, Paper 82-1B, p. 147-151.

Piper, D.J.W. and Sparks, R., 1985. A complex Quaternary slide on the Scotian Slope (Manuscript).

Prior, D.B., Coleman, J.M. and Doyle, E.H., 1984. Antiquity of the continental slope along the middle-Atlantic margin of the United States, Science, V. 223, pp. 926-928

Seaconsult Marine Research Ltd., 1978. Analysis of Ocean Currents, Flemish Pass. Report to Imperial Oil Ltd., 164pp.

Schafer, C.T., Tan, F.C., Williams, D.F., and Smith, J.N., 1985. Late Glacial to Recent stratigraphy, palaeo and sedimentary processes, Newfoundland Continental Slope and Rise. Can. J. Earth Sciences. V. 22 (2), pp.266-282.

Stanley, D.J., Swift, D.J.P., Silverberg, N., James, N.P. and Sutton, R.G., 1971. Recent sand spillover off Sable Island Bank, Scotian shelf., Earth Science Sympsoium on Offshore Eastern Canada. Geological Survey of Canada, Paper 71-23, pp. 167-194.

LIST OF FIGURES

Figure 1 — Generalized bathymetry and location map of survey area showing ship's track for Phase I on cruise HU84-035. Broken lines are survey track for Huntec high resolution seismic reflection profile (DTS) collected on cruise HU80-010.

Figure 2 — Map showing key to location of seismic lines illustrated in figures described in the text (numbers in this figure refer to figure numbers in text).

Figure 3 — Map showing interpreted principal geomorphological features of the survey area including position of core 3-1.

Figure 4 — Huntec DTS profile showing iceberg scoured well stratified sediment.

Figure 5 — Huntec DTS profile illustrating shallow trough, which marks the lower limit of iceberg scouring at about 725 m water depth.

Figure 6 — Huntec DTS profile illustrating the relief, and hummocky terrain of the slope deposits (blank spaces on profile indicate that during these intervals data were not being collected).

Figure 7 — 12 kHz bathymetric profile illustrating iceberg scour relief, and showing their disappearance both on the continental shelf edge and below the upper slope.

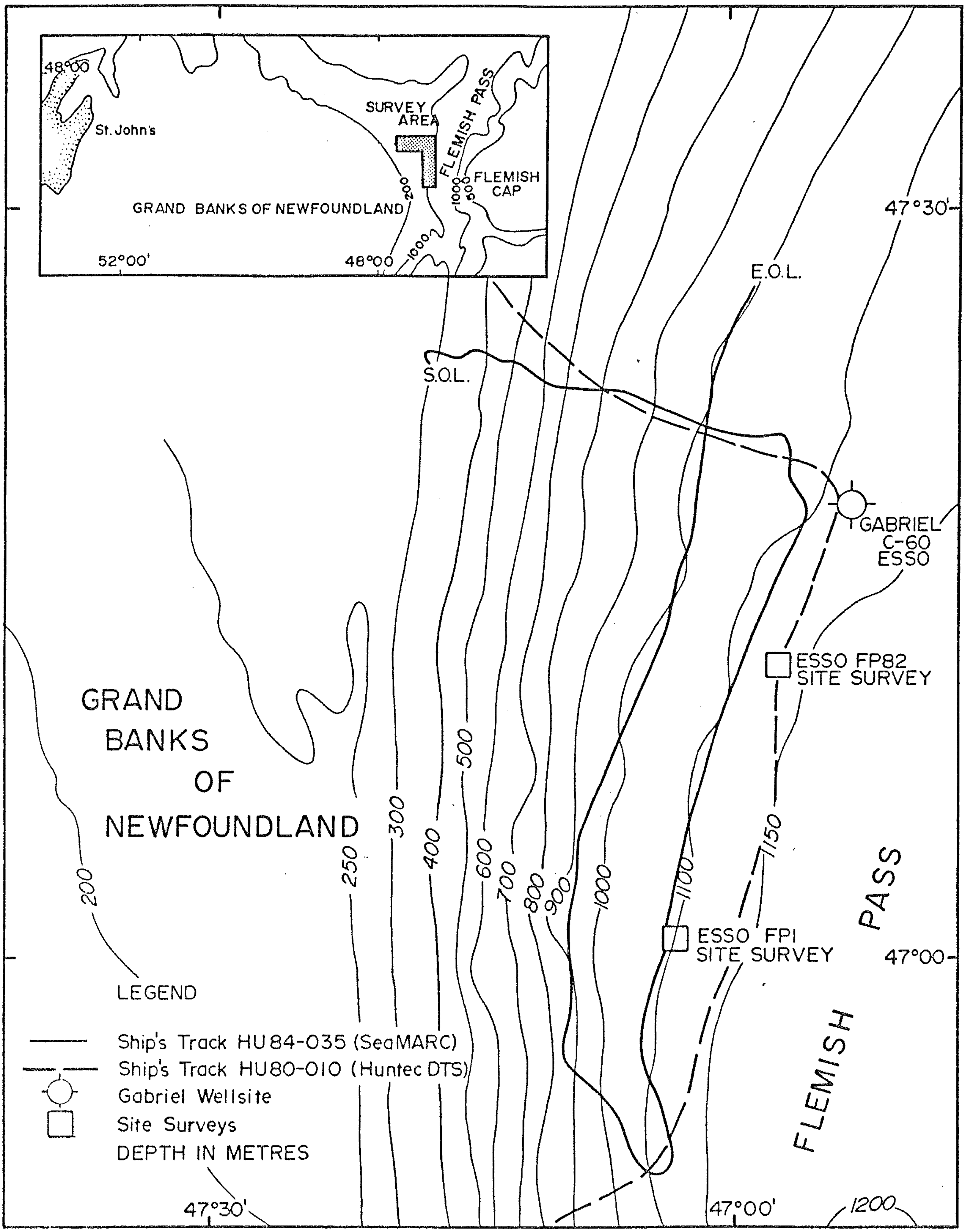
Figure 8 — Sidescan sonograph illustrates the extensively scoured seabed on the upper slope. Broken line separates the two scour populations. Upper population to the left of the broken line.

Figure 9 — 12 kHz bathymetric profile showing the low relief, mid-continental slope area. Mass-flow deposit sediment can be seen at the base of, and along the floor of the pass.

Figure 10 — Sidescan sonograph illustrating area of mass-flow deposit accumulations. Note fragmentation of 'lineated' mass-flow deposit toward the southern end in figure 10b.

Figure 11	Huntec DTS profile collected 2.7 km upslope from the mass-flow deposit illustrating acoustic character suggesting the existence of a 3 km long scar slide.
Figure 12	Sidescan sonograph showing the two mound-like features which have small lineations radiating out and downward from the crest (see Figure 13). Also seen on the starboard sidescan channel is a small slide scar.
Figure 13	Huntec DTS profile illustrating the two prominent 'mounds' (A), of unknown origin. Also evident, are a similar feature to the north (X), and a much smaller buried one to the south of the survey line (Y).
Figure 14	Sidescan sonograph illustrating a major ENE to WSW trending scarp, a major slide scar and a possible bedding plane slide complex adjacent to the scarp.
Figure 15	Huntec DTS profile illustrating a scarp situated on the mid-continental slope, upslope from the slumped deposits.
Figure 16	Sidescan sonograph illustrating prominent linear scarps. The scar on the port sidescan channel is found on the lower-mid continental slope (see also Figure 15), whereas that seen on the starboard sidescan channel occurs near the junction between the lower continental slope and the floor of Flemish Pass (see also Figure 17).
Figure 17	Sidescan sonograph illustrating the same lower continental slope scarp seen in Figure 16; the scarp crosses over from the port to the starboard side; a ridge-like feature is also evident only on the port side.
Figure 18	4.5 kHz profile showing a 7 km wide depression (channel) between the linear scarp and smaller ridge illustrated in Figure 17.
Figure 19	Sidescan sonograph illustrating a feature interpreted as a relict gully. The starboard channel swath illustrates a feature which may either be an erosional channel or a slide bedding plane complex.
Figure 20	The Sea MARC 4.5 kHz profile reveals a 190 m hill, situated in the southern section of the survey.

Figure 21	The Sea MARC 4.5 kHz profile which traverses the lower continental slope, along the length of the pass illustrates the gentle undulatory form of the seabed.
Figure 22	Huntec DTS profile illustrating sediment waves developed in well stratified sediment. Note the irregular cross-section and slight up-section migration of the wave crests to the southwest.



48°00
St. John's
SURVEY AREA
FLEMISH PASS
FLEMISH CAP
GRAND BANKS OF NEWFOUNDLAND
200
1000
500
1000
52°00'
48°00
47°30'
E.O.L.
S.O.L.
GABRIEL C-60 ESSO
ESSO FP82 SITE SURVEY
ESSO FPI SITE SURVEY
GRAND BANKS OF NEWFOUNDLAND
FLEMISH PASS
200
250
300
400
500
600
700
800
900
1000
1100
1150
1200
47°00'
47°30'
47°00'
LEGEND
Ship's Track HU84-035 (SeaMARC)
Ship's Track HU80-010 (Huntec DTS)
Gabriel Wellsite
Site Surveys
DEPTH IN METRES

Figure 1

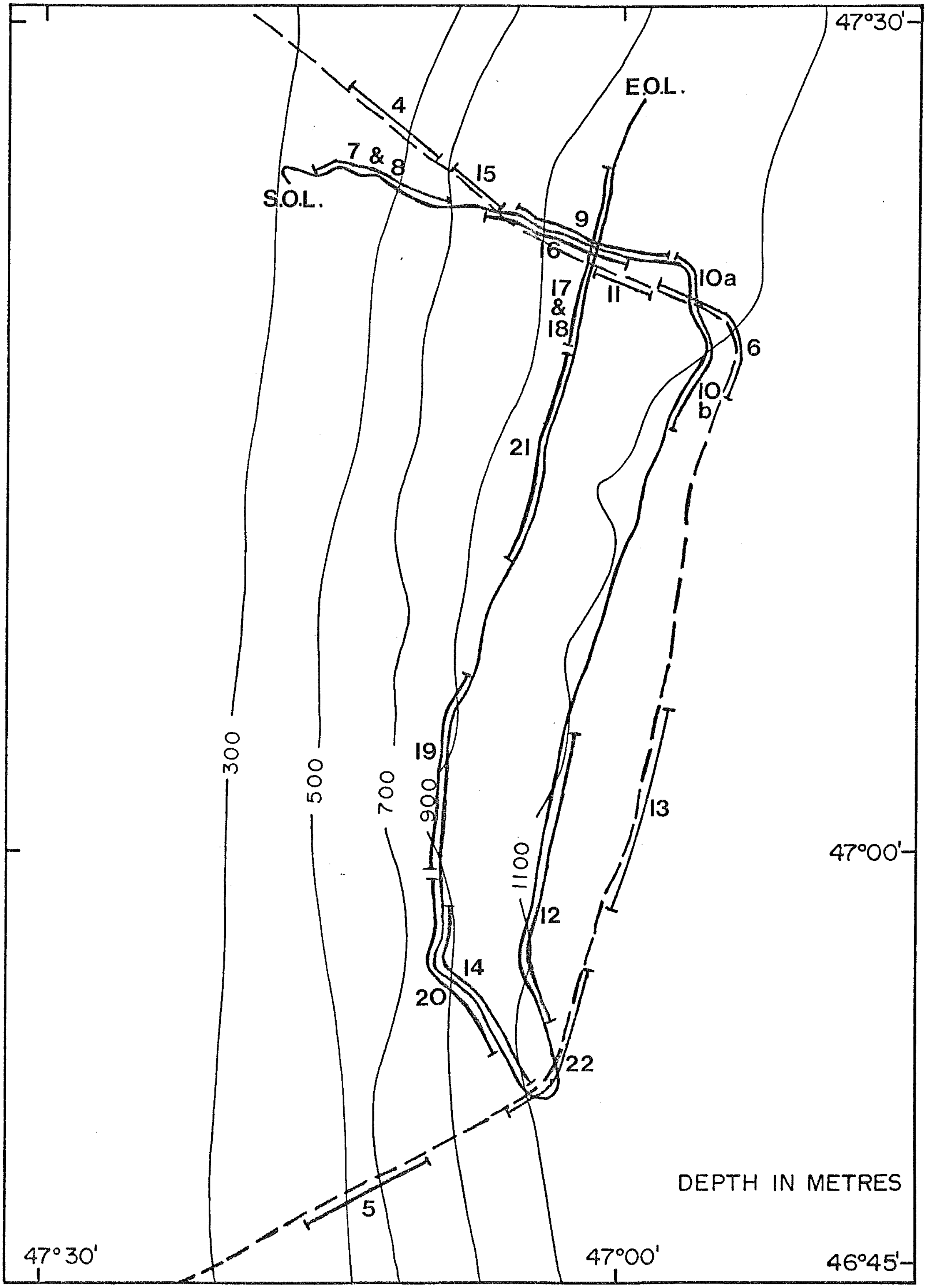

47°30'
E.O.L.
4
7 & 8
15
S.O.L.
9
16
10a
17
&
18
11
6
10
b
21
19
300
500
700
900
13
47°00'
1100
12
14
20
22
DEPTH IN METRES
5
47°30'
47°00'
46°45'

Figure 2

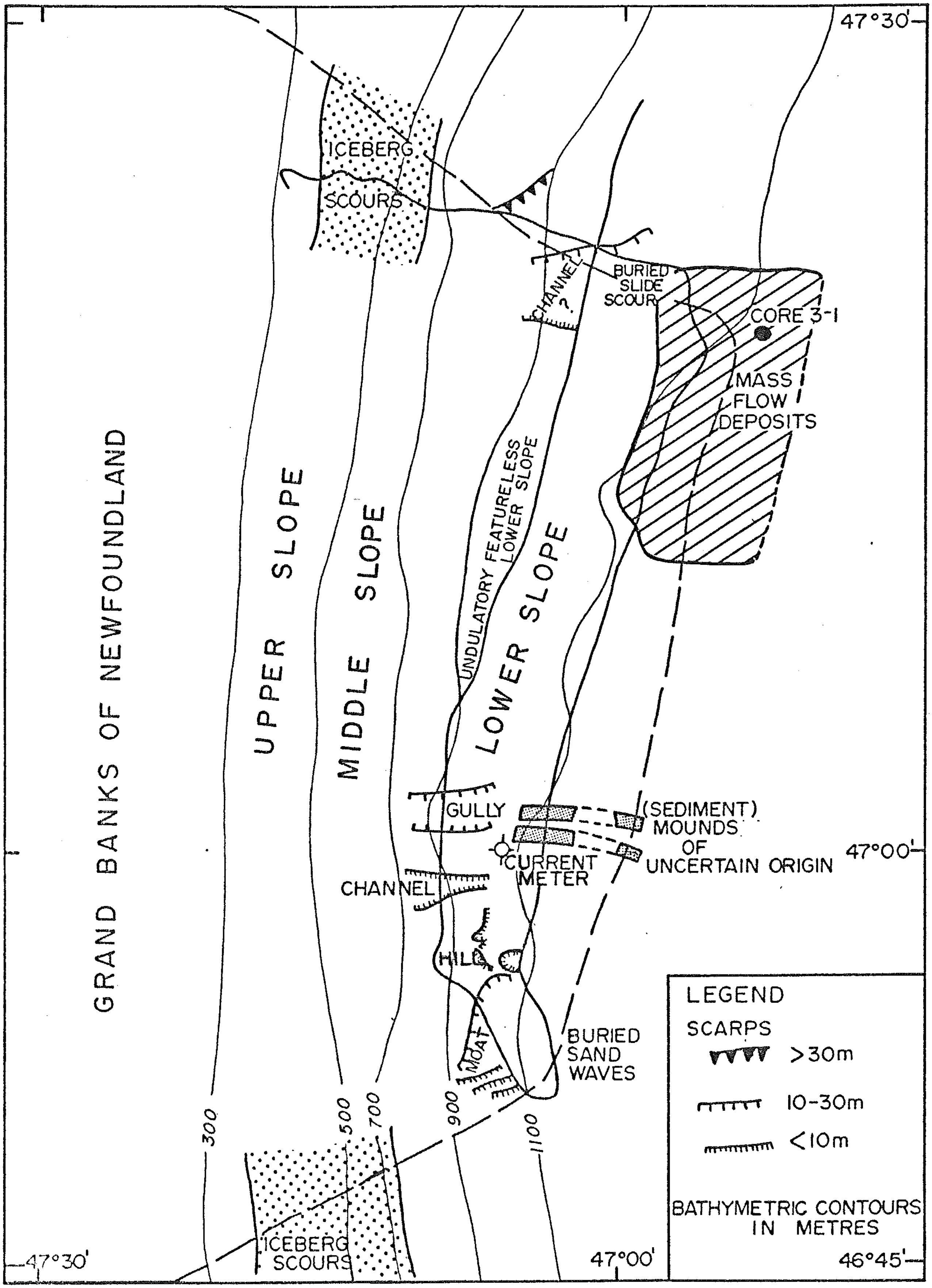

47°30'
ICEBERG
SCOURS
CHANNEL ?
BURIED SLIDE SCOUR
CORE 3-1
MASS FLOW DEPOSITS
GRAND BANKS OF NEWFOUNDLAND
UPPER SLOPE
MIDDLE SLOPE
UNDULATORY FEATURELESS LOWER SLOPE
LOWER SLOPE
GULLY
(SEDIMENT) MOUNDS OF UNCERTAIN ORIGIN
47°00'
CURRENT METER
CHANNEL
HILL
MOAT
BURIED SAND WAVES
300
500
700
900
1100
ICEBERG
SCOURS
47°30'
47°00'
46°45'
LEGEND
SCARPS
>30m
10-30m
<10m
BATHYMETRIC CONTOURS IN METRES

Figure 3

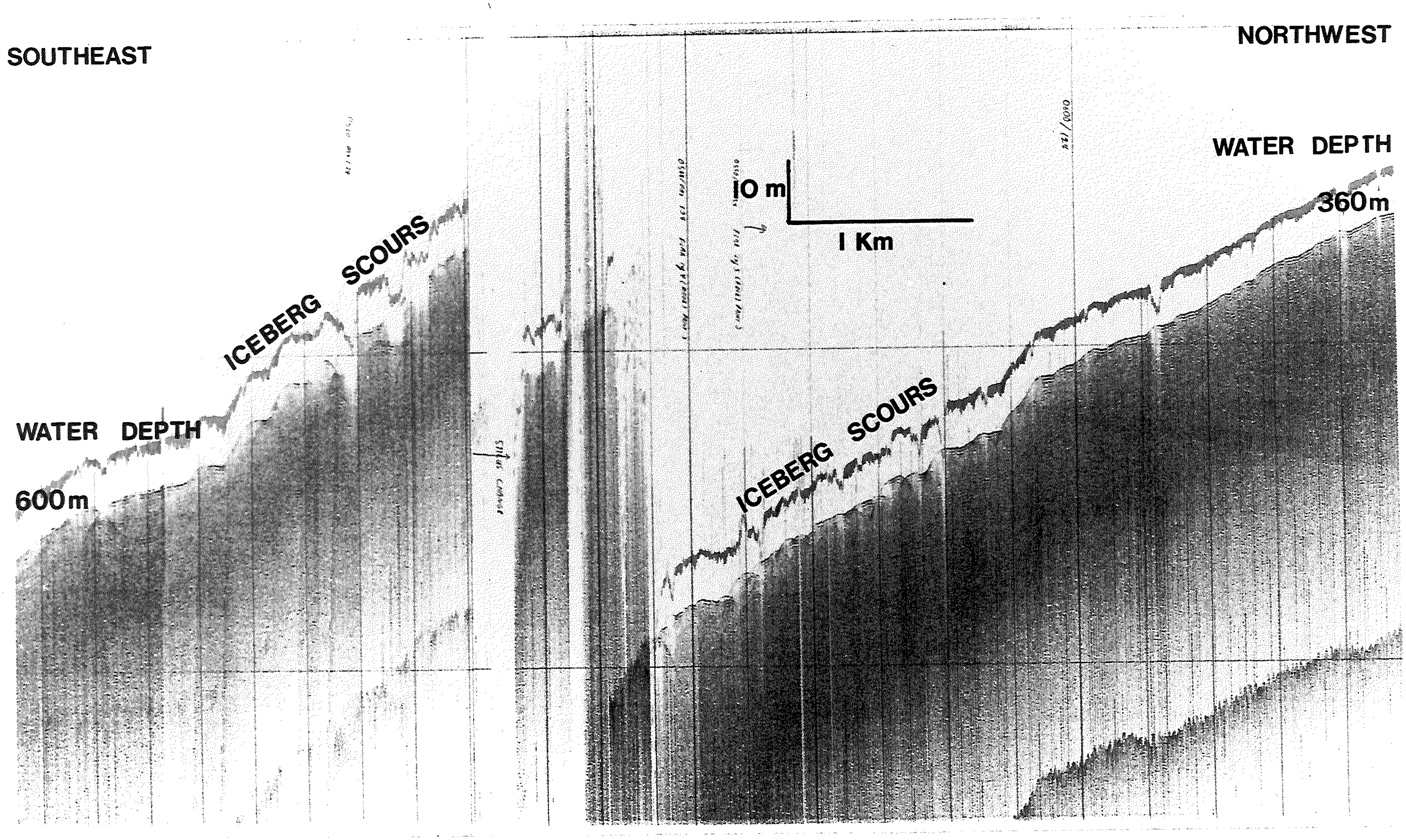

SOUTHEAST
NORTHWEST
WATER DEPTH
360m
10 m
1 Km
ICEBERG SCOURS
WATER DEPTH
600m
ICEBERG SCOURS

Figure 4

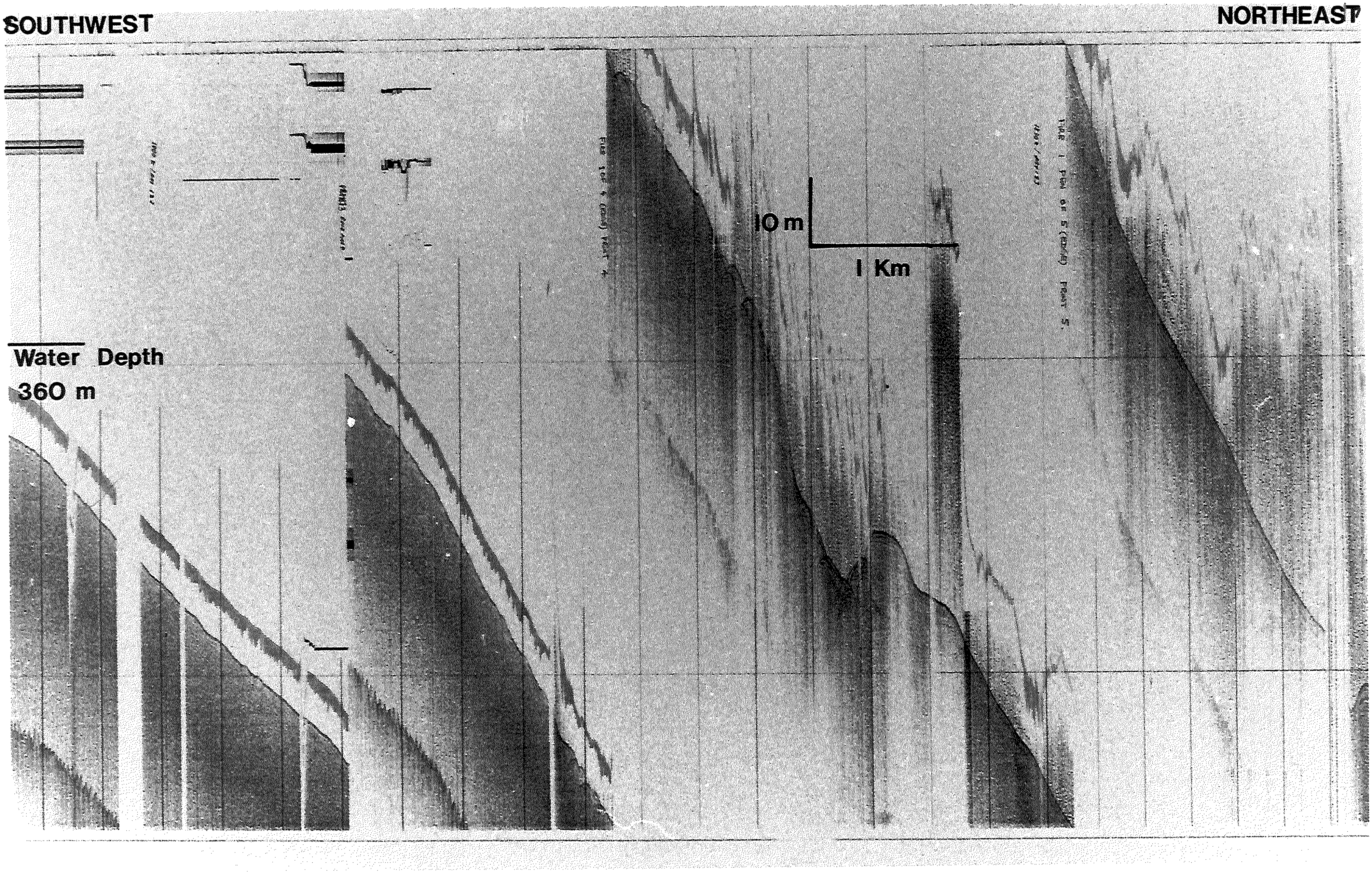


Figure 5

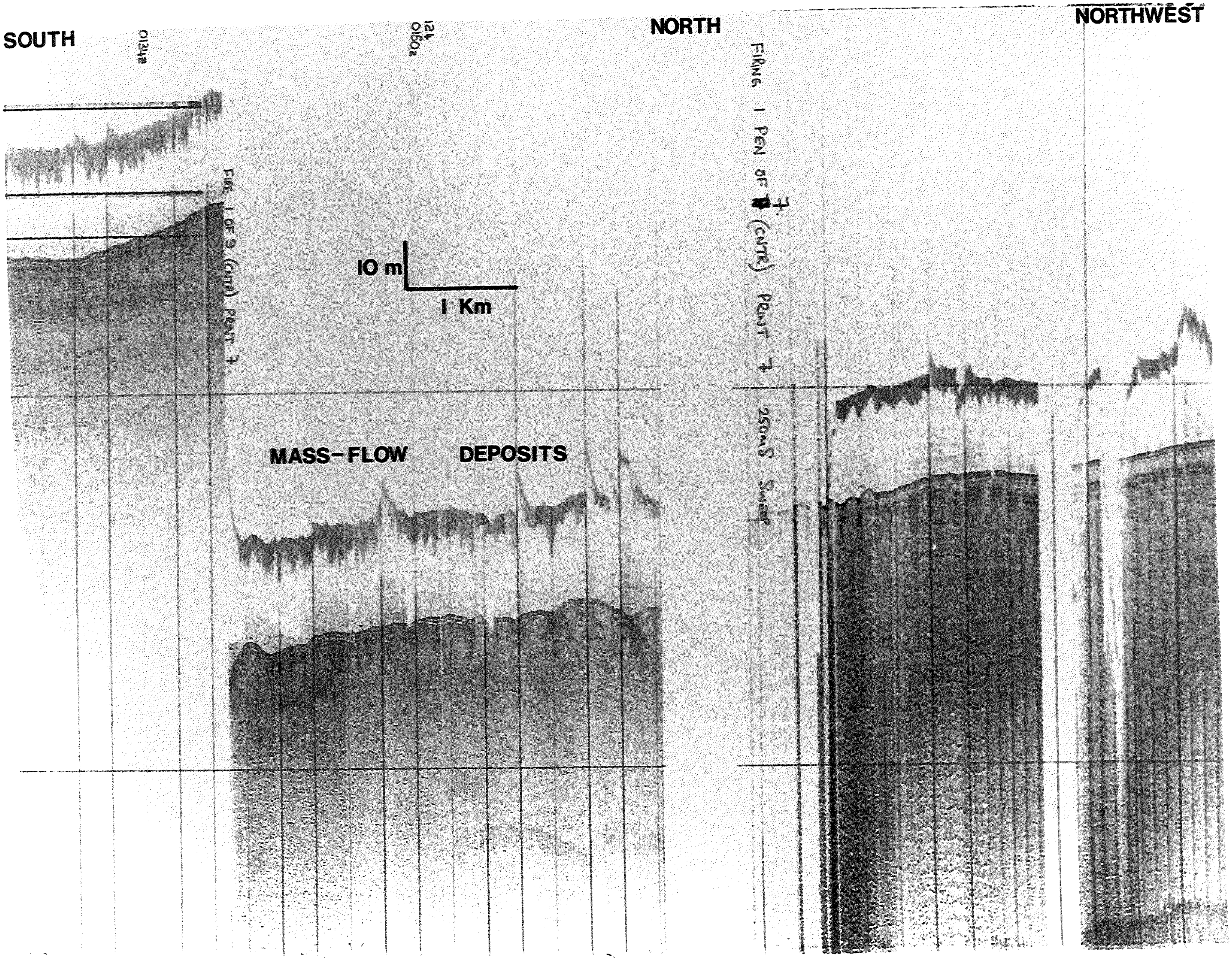


Figure 6

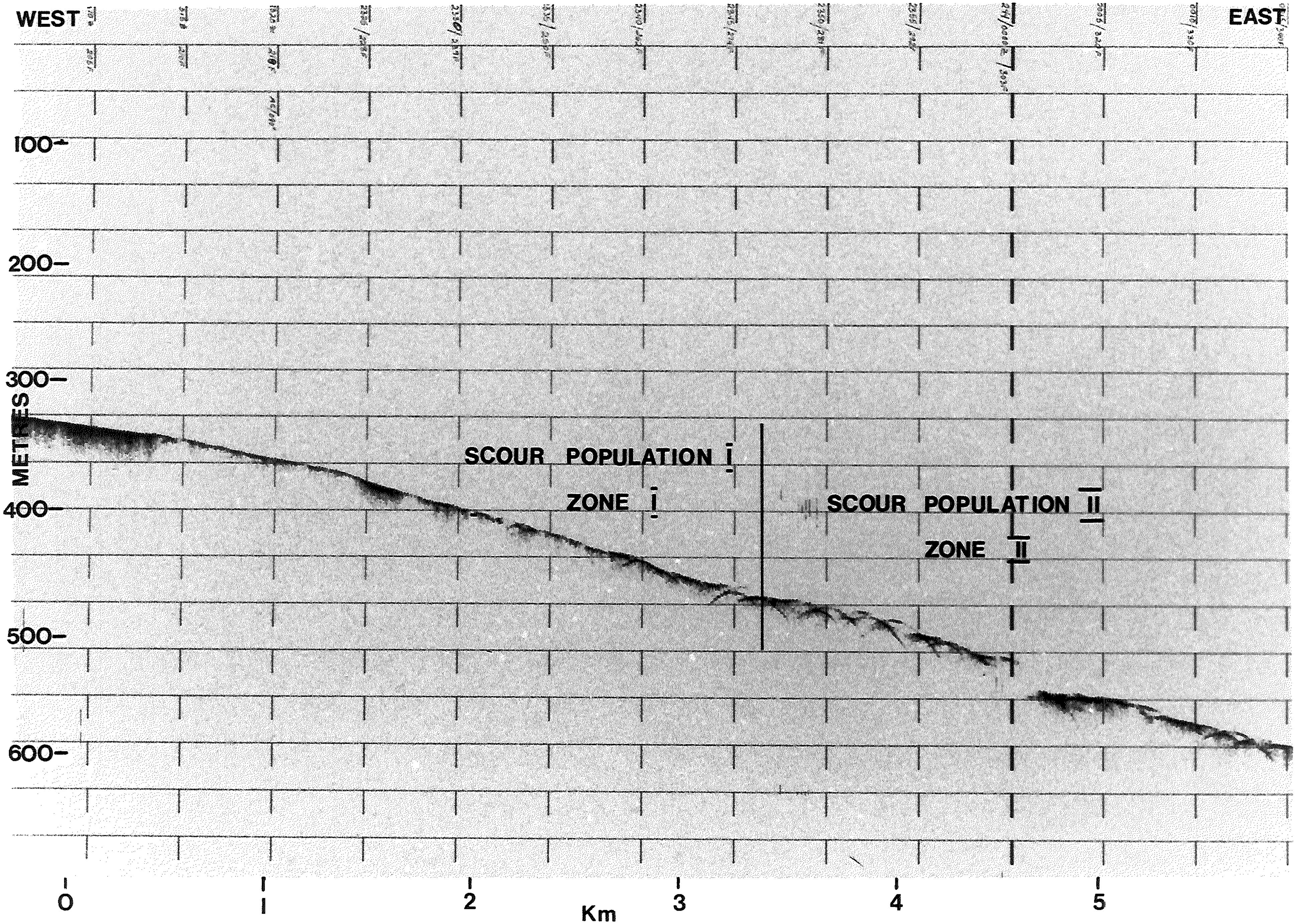

WEST
EAST
100
200
300
400
500
600
METRES
SCOUR POPULATION I
ZONE I
SCOUR POPULATION II
ZONE II
0
1
2
3
4
5
Km

Figure 7

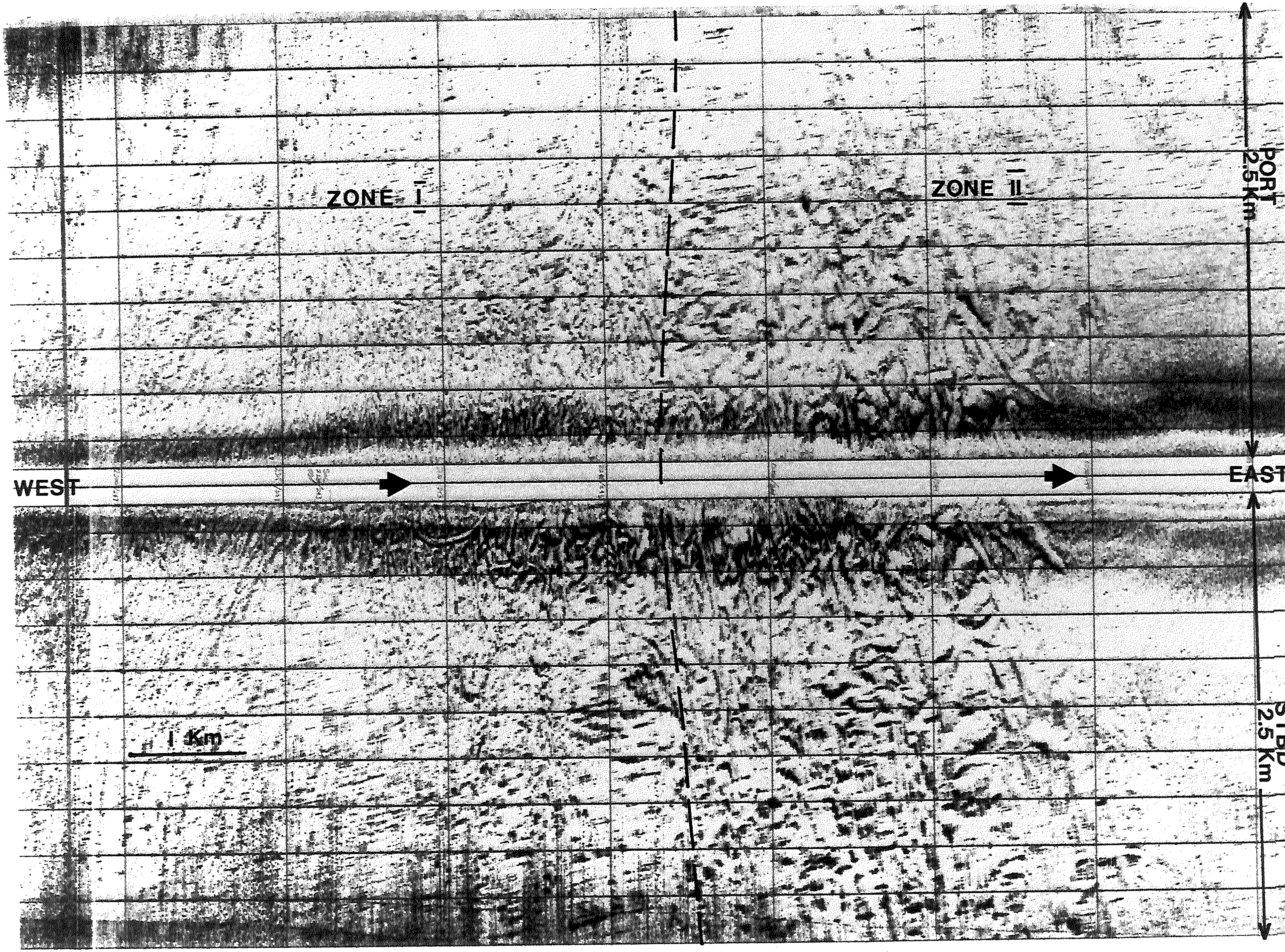


Figure 8

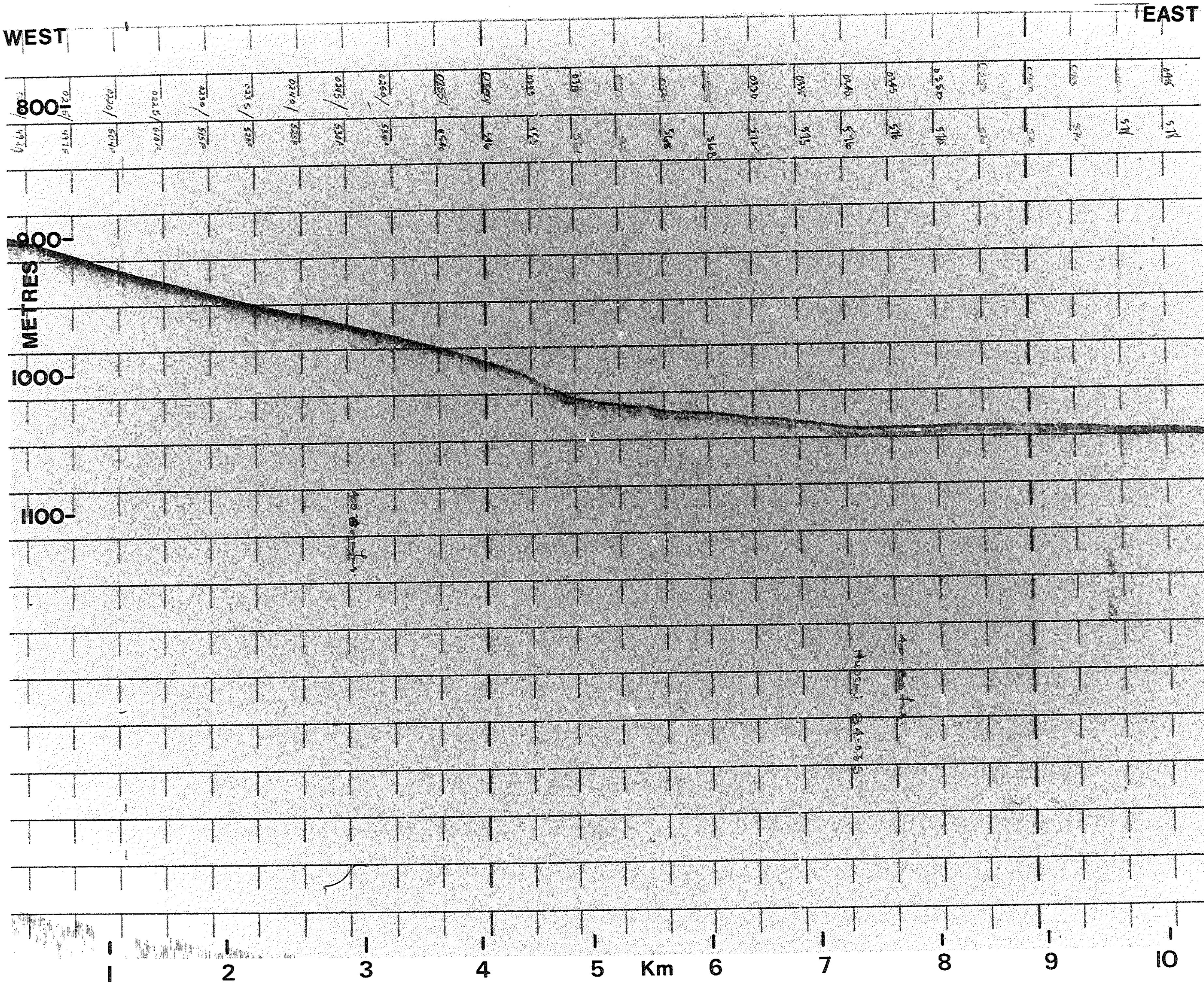


Figure 9

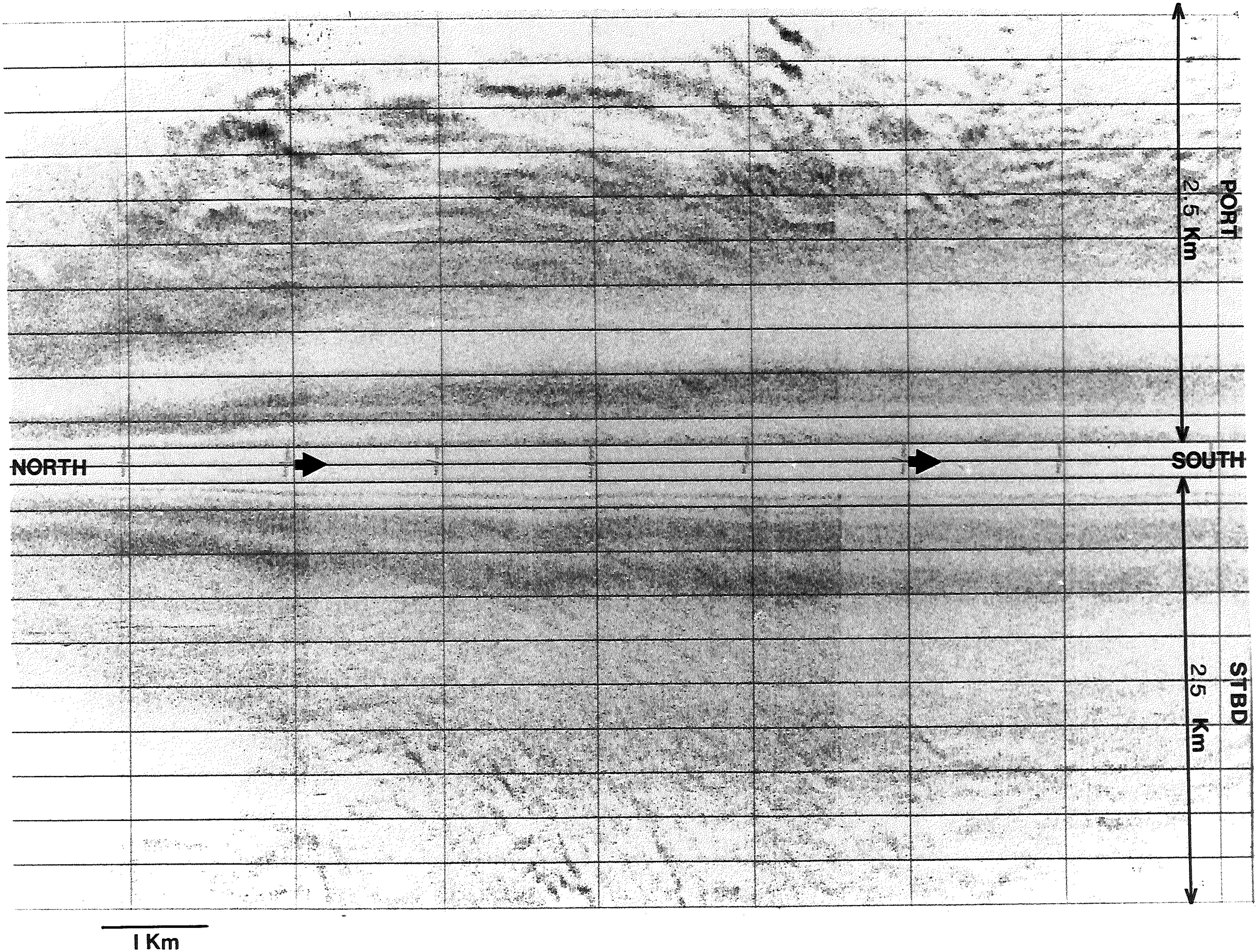


Figure 10a

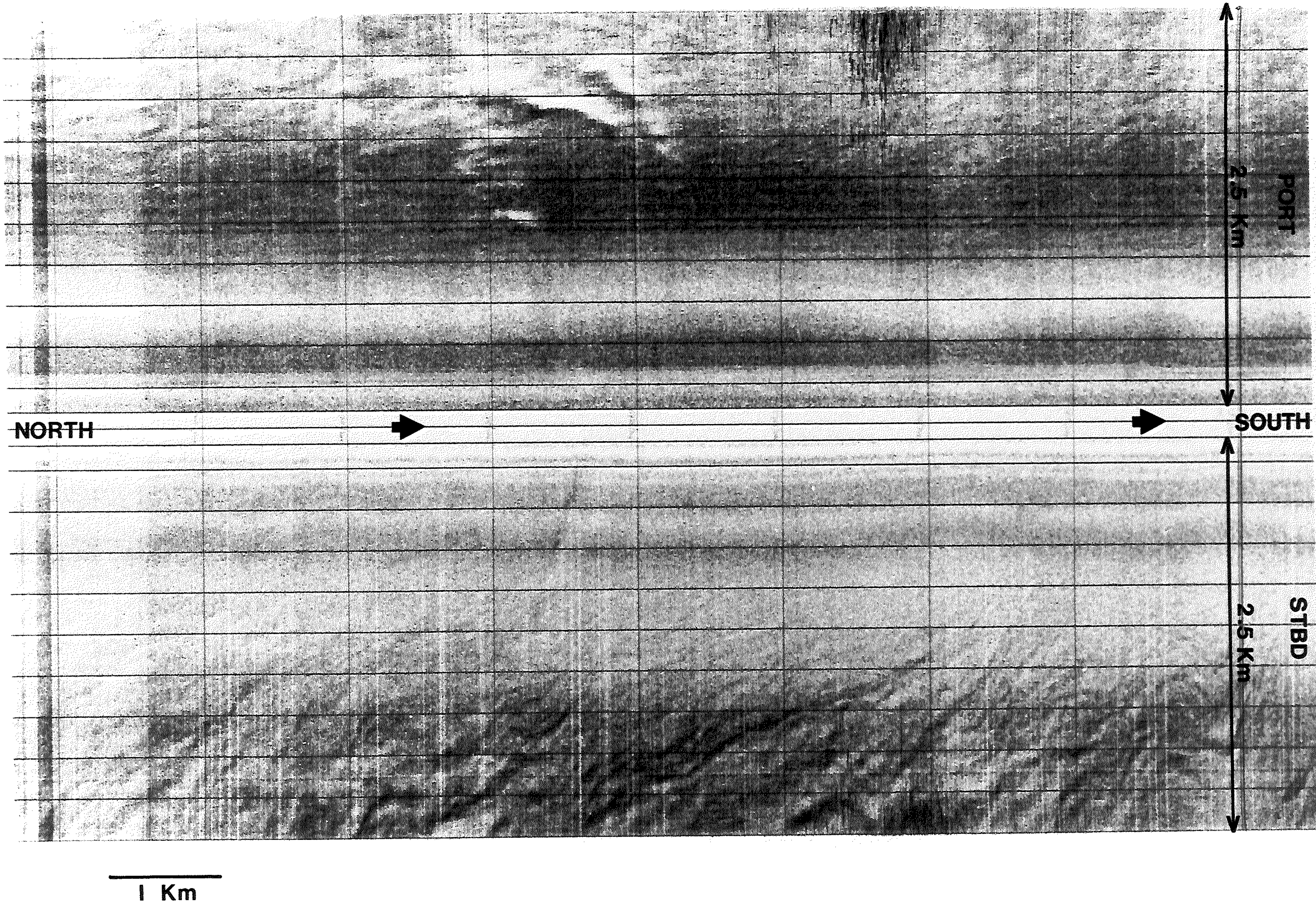


Figure 10b

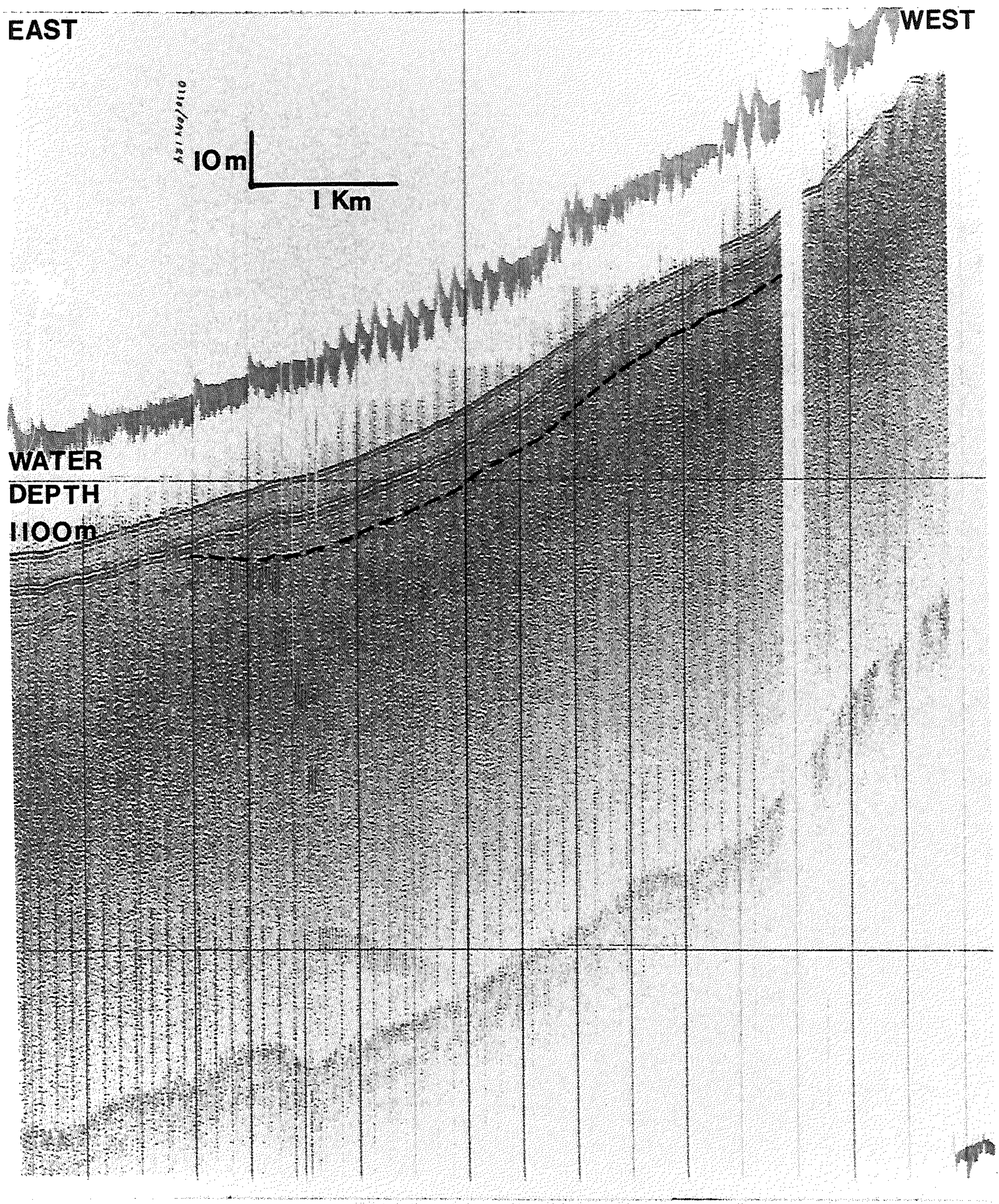


Figure 11

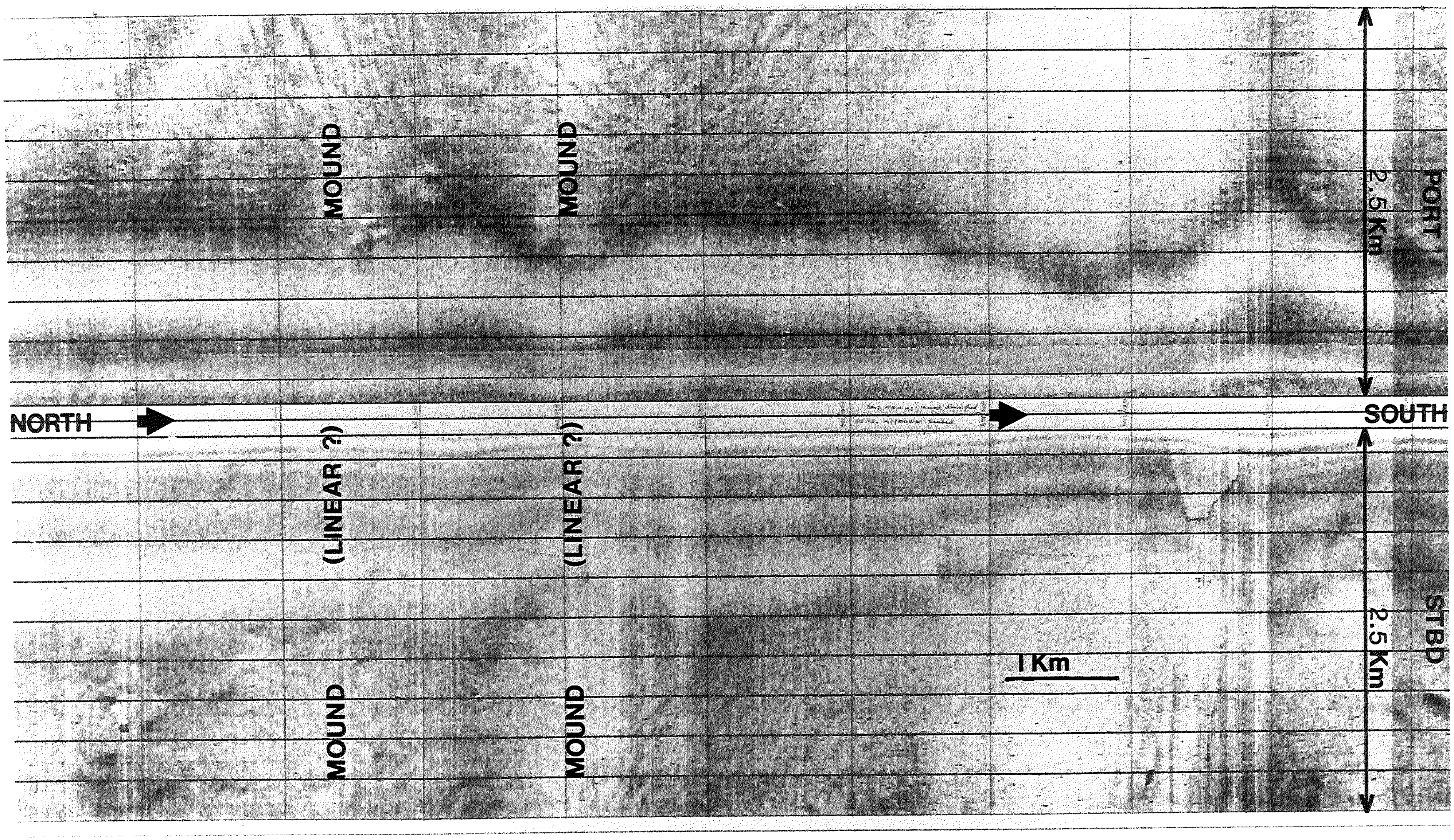

MOUND
MOUND
PORT
2.5 Km
NORTH
SOUTH
(LINEAR ?)
(LINEAR ?)
STBD
2.5 Km
1 Km
MOUND
MOUND

Figure 12

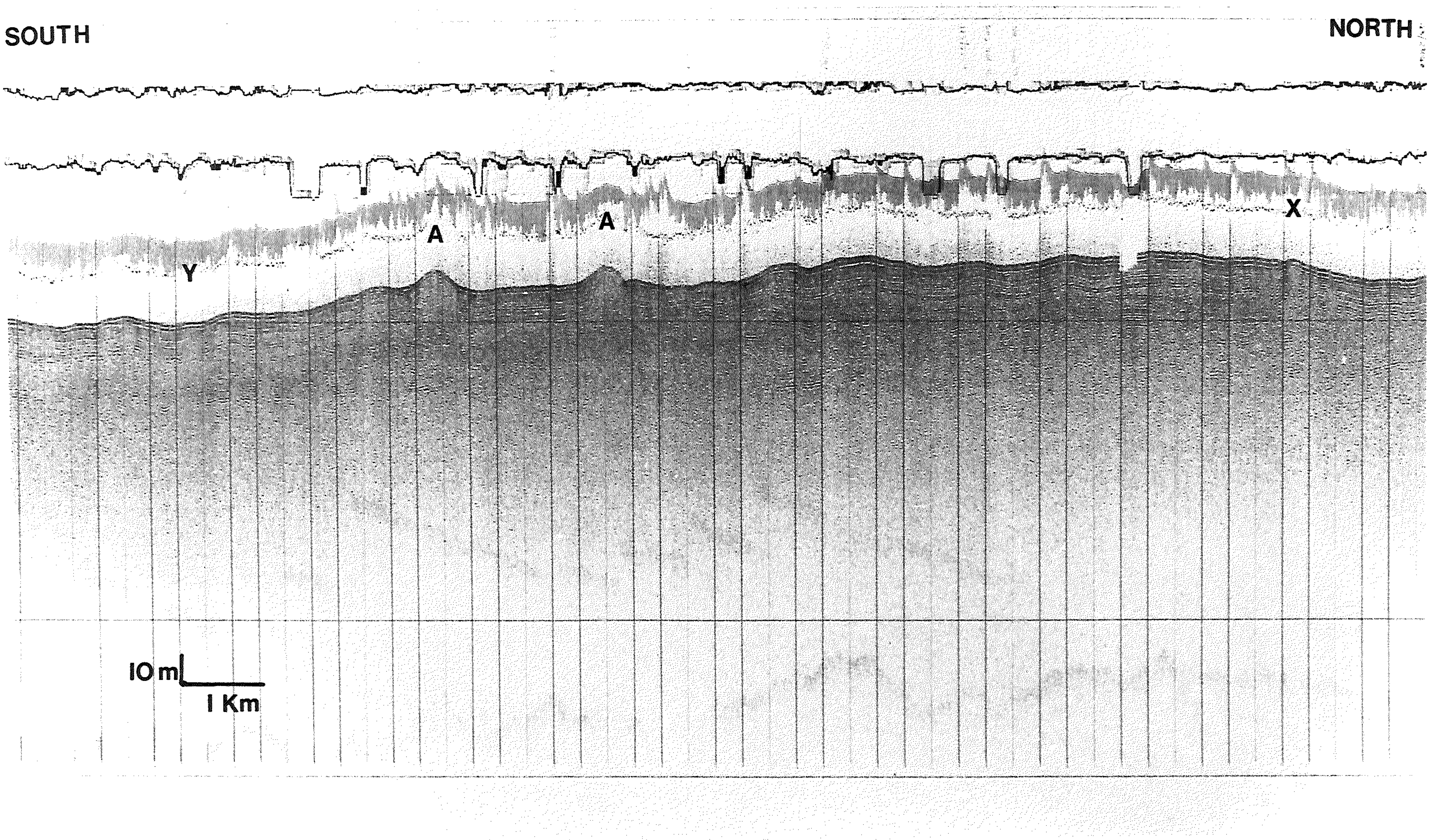


Figure 13

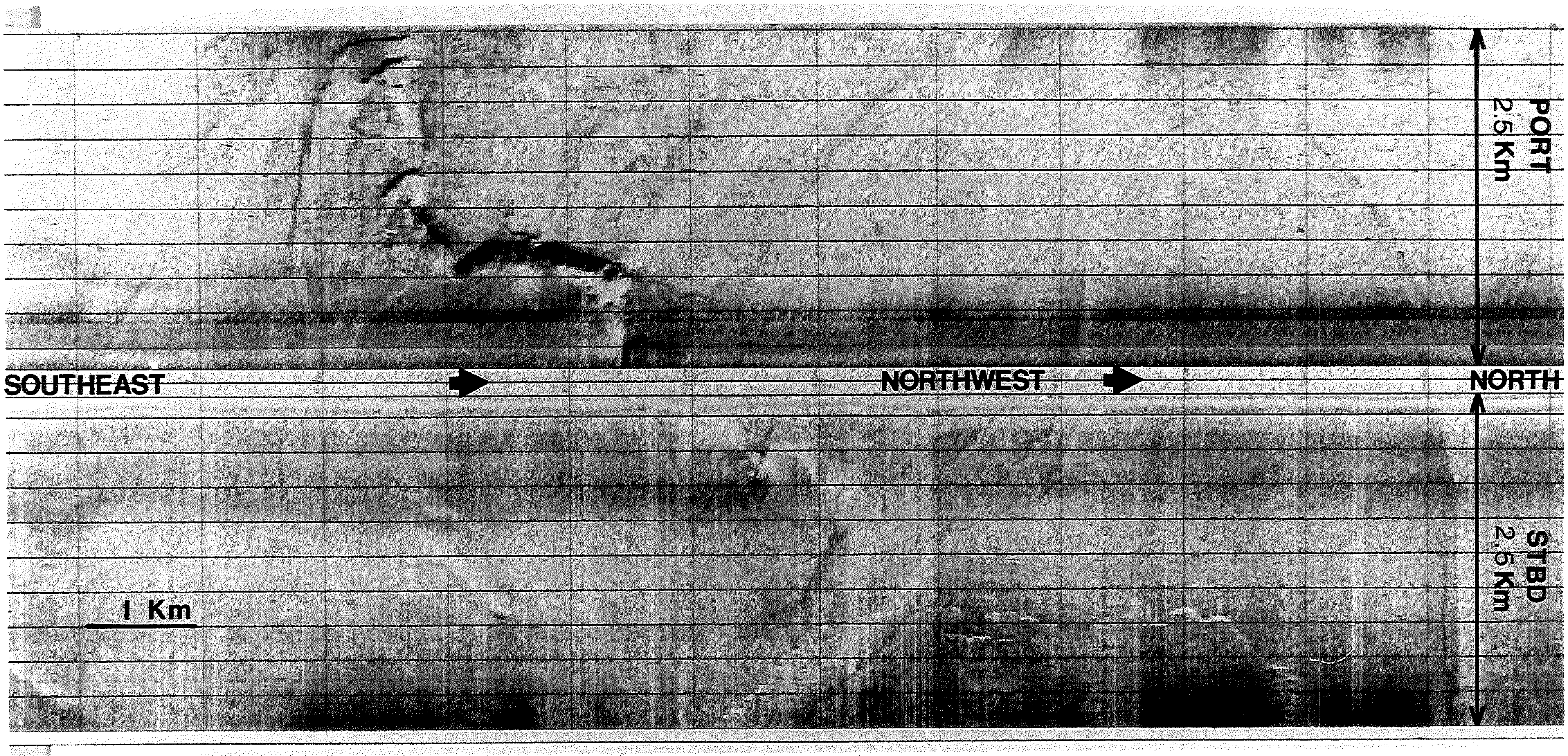


Figure 14

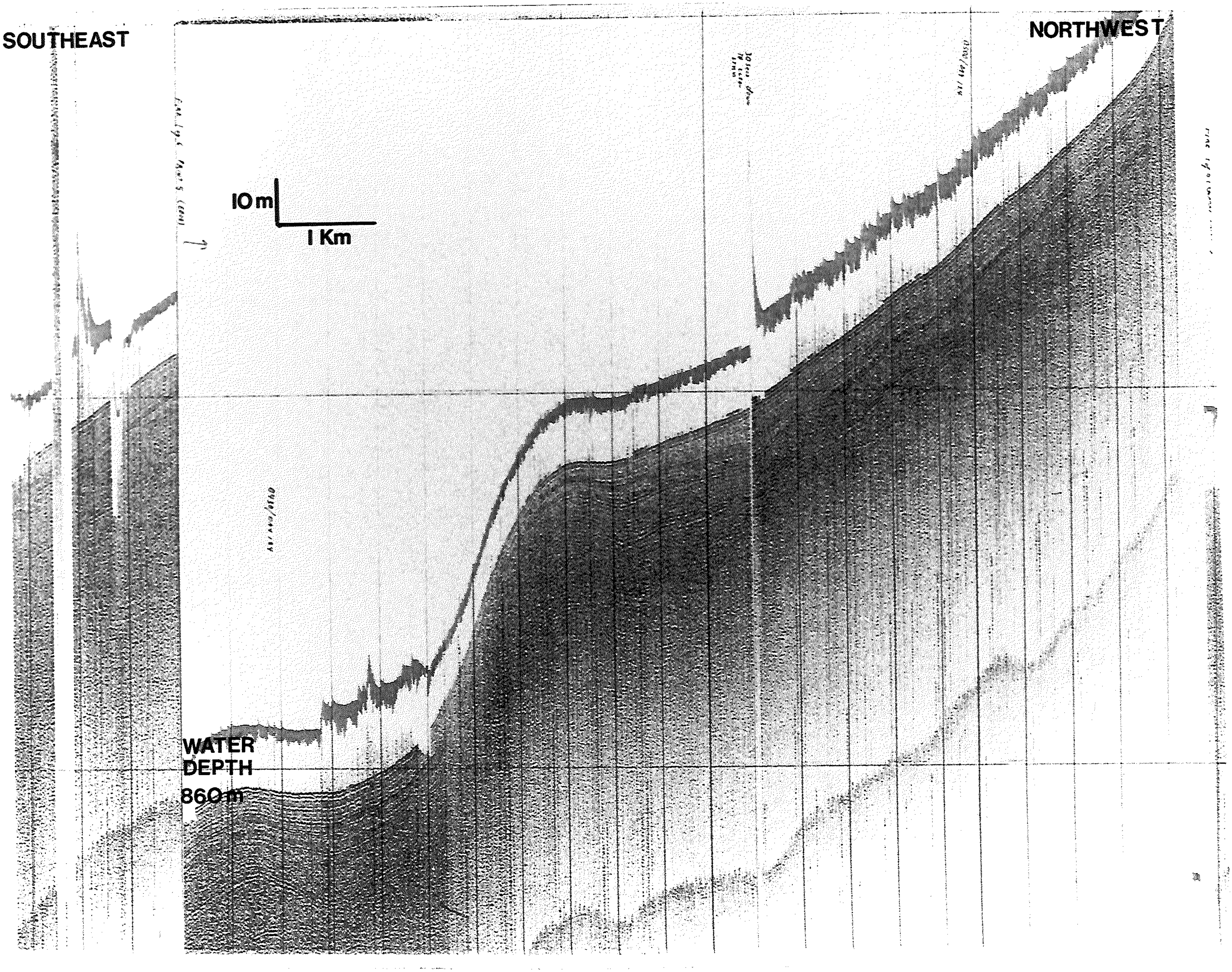


Figure 15

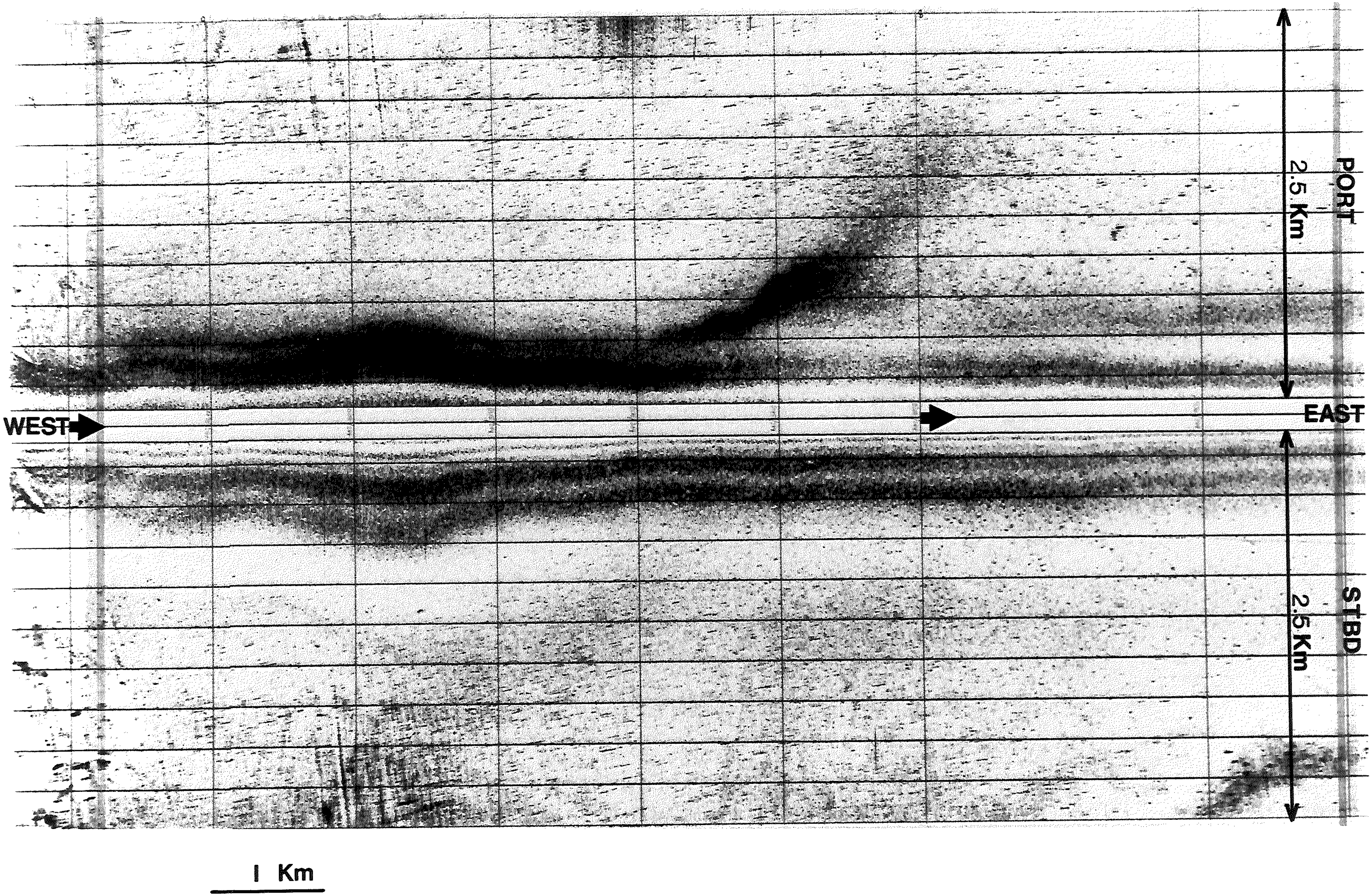


Figure 16

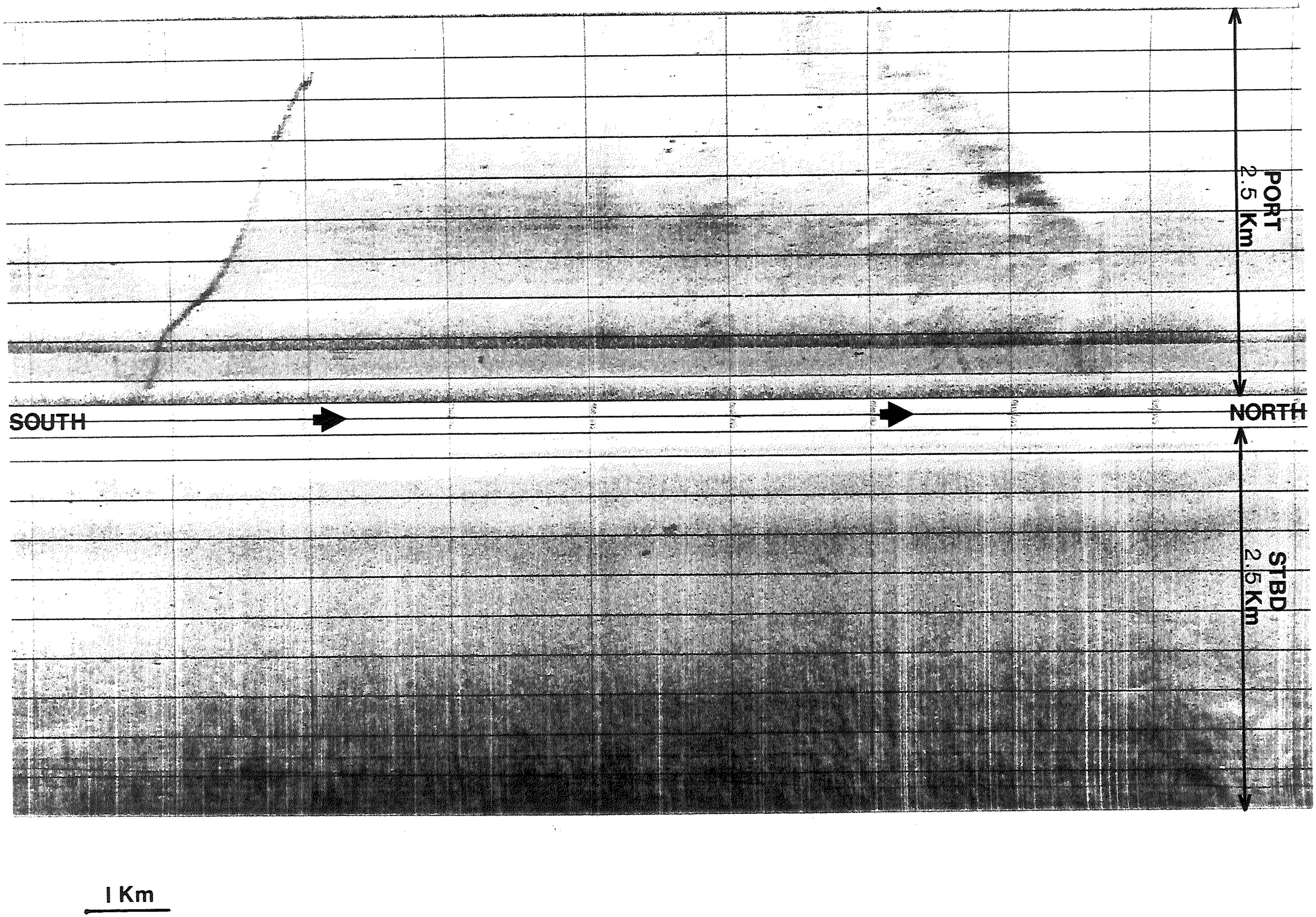


Figure 17

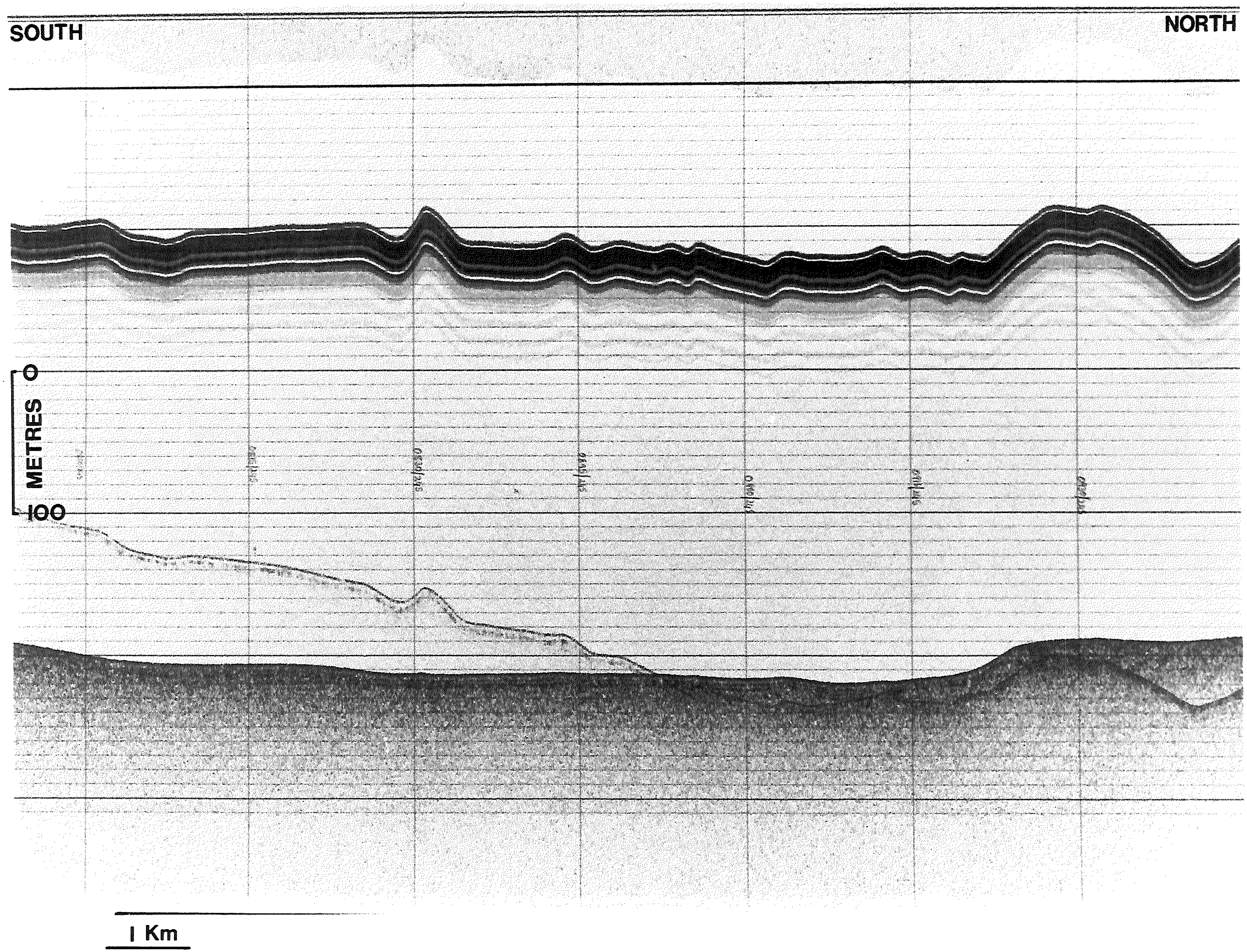


Figure 18

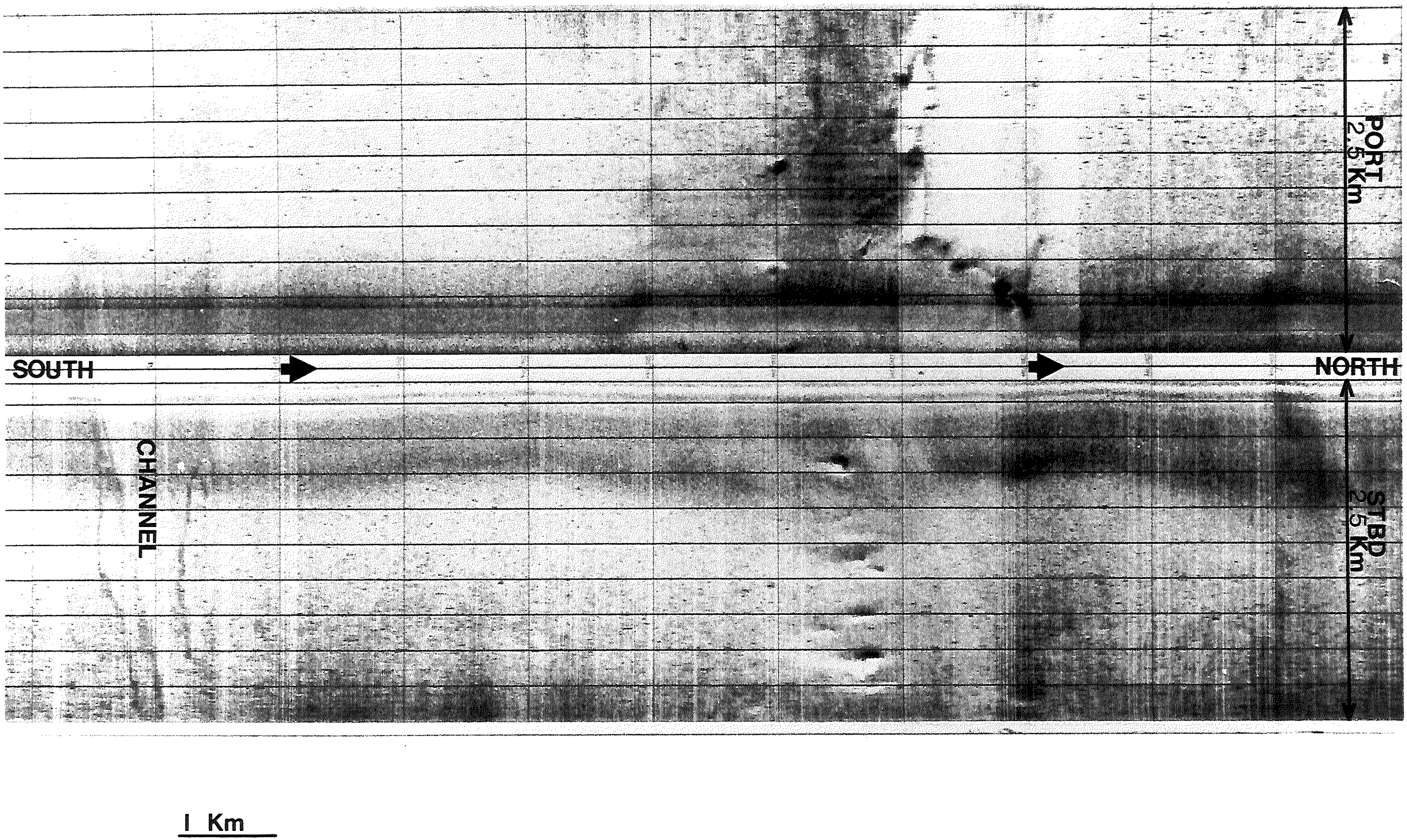


Figure 19

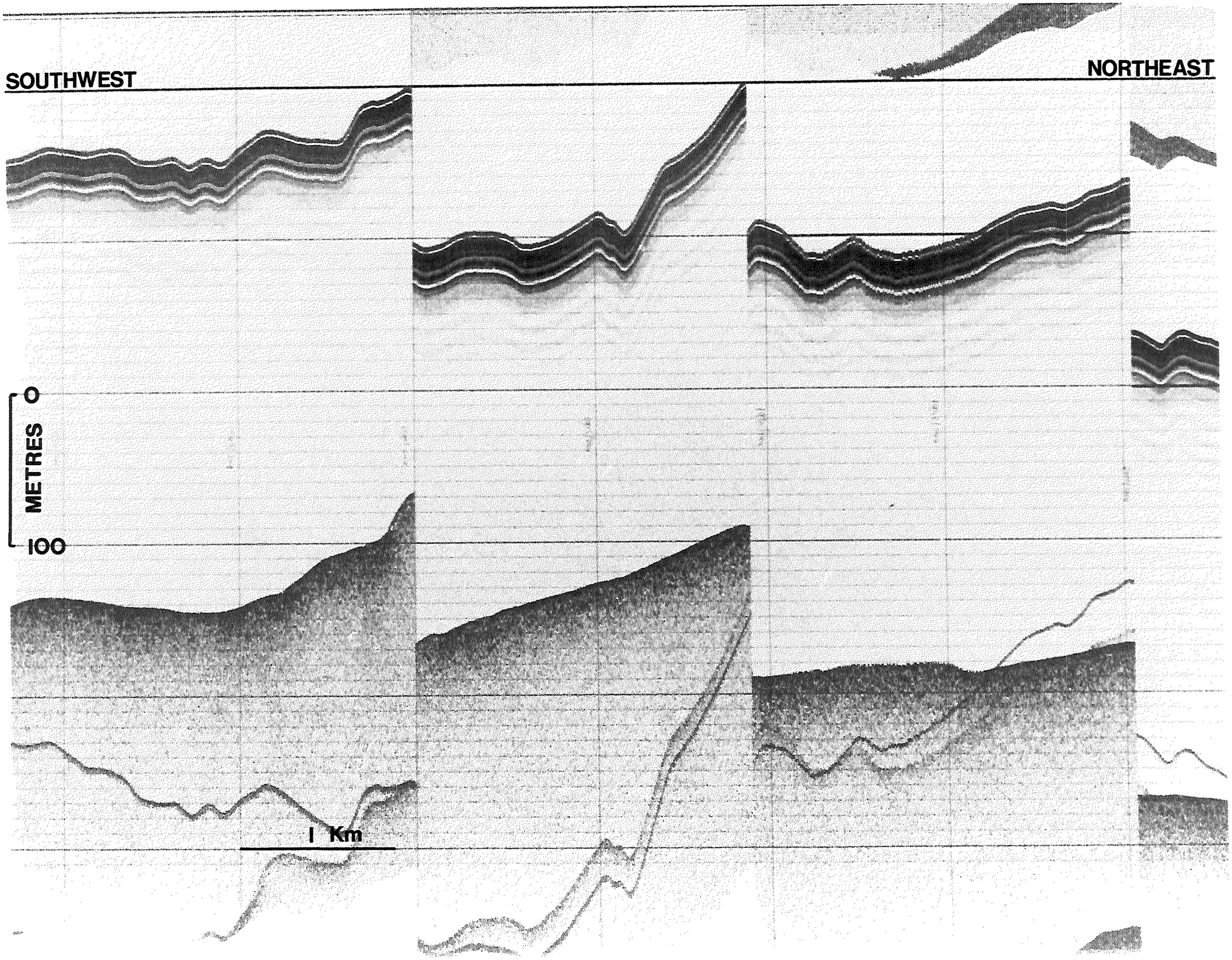


Figure 20

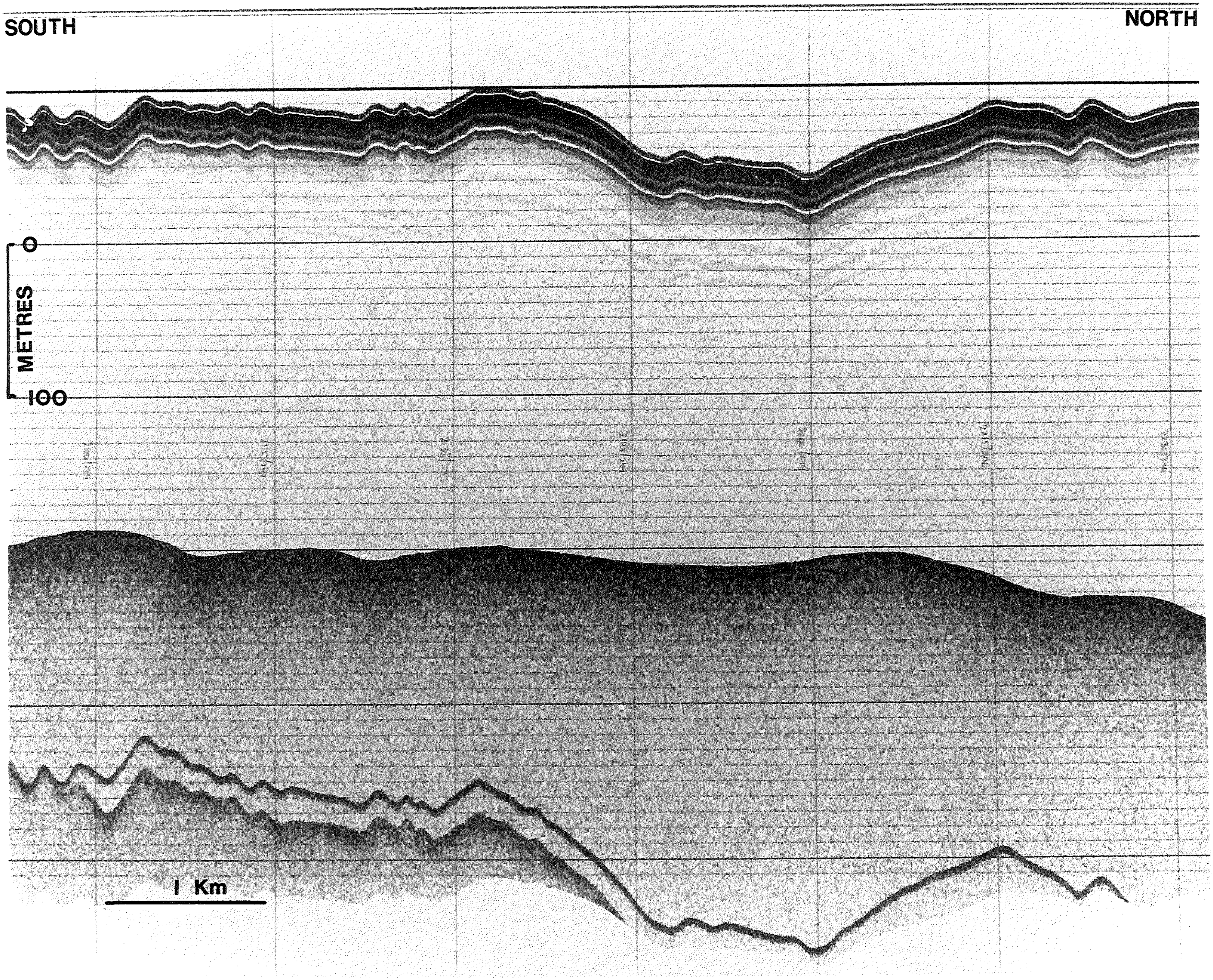


Figure 21

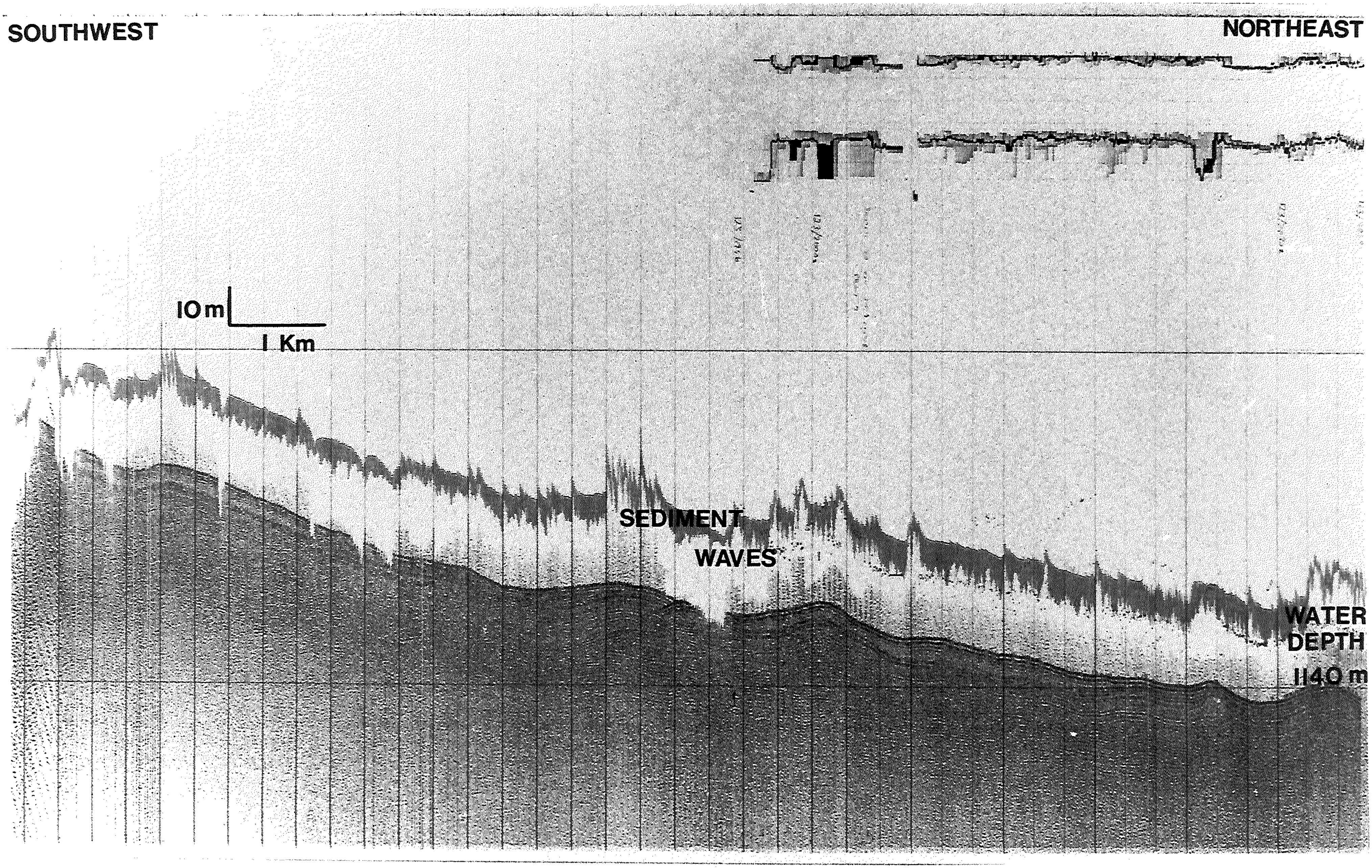

SOUTHWEST
NORTHEAST
10m
1 Km
SEDIMENT
WAVES
WATER
DEPTH
1140 m

Figure 22